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An Adventure in Research: Copper-Oxide Rectifiers and Their Applications

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THE first portion of this account might be entitled "How Fate or Fortune Leads a Laboratory Worker to an Interesting Result." The story may be worth telling as an illustration of the fact that fortunate circumstances often play an important part in the work of an investigator. It is only necessary to see opportunities when they arise.

In 1920 the rectifiers used most extensively in the low-capacity field were the aluminum electrolytic rectifiers and the vibrating reed rectifiers. Both had a comparatively short life. Their efficiencies were low, 20 percent being considered reasonably good. The vibrating reeds needed frequent adjustments and the aluminum electrolytic units, frequent replacement. Rectifiers with moving parts or an electrolyte are unreliable and dependent on frequent inspections and careful maintenance. The current and the voltage ranges over which they were useful were very small. The output was so unreliable that there was no thought of using them in instruments or other circuits in which the output had to be constant. There were other rectifiers, such as rotating commutators, which were useful in special applications, and solid electrolytic rectifiers which were known but not extensively applied. The hot-cathode rectifiers, whether used in a vacuum or with a vapor, were limited in their applications because of their electrical characteristics.

Before 1920 a number of investigators with the imagination to visualize the possibilities had been making efforts to develop a practical rectifier from solid materials. Their efforts had not been successful or promising.

It was the good fortune of the writer to be assigned to a problem that had nothing directly to do with rectifiers but that led to the discovery of the copper-oxide barrier layer and the development of many of its possibilities. The problem, proposed by Mr. L. F. Howard, Chief Engineer of this company, was to study the possibilities of developing a relay without moving parts and circuits in which it could be used. Relays are used in great numbers as the most essential portion of signaling systems.

The possibility of using the change in resistance of certain compounds with change in illumination or with change in temperature immediately suggested itself. It was known that cuprous oxide was light-sensitive in that its resistance decreased when it was illuminated. The copper-oxide light-sensitive cells then in existence had very high resistances and were used only for the small currents that can be measured with a sensitive galvanometer. The problem here seemed to be to develop a unit that would carry considerably larger currents and that would have a sufficient change in resistance with illumination to turn this current on or off.

Cuprous oxide recommended itself because of the ease of production but seemed to have the disadvantage of being very brittle so that it is difficult to mount it and at the same time make good contact with it. It was then thought that the cuprous oxide could be formed on a plate of

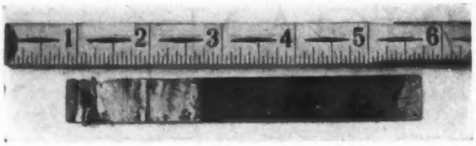

FIG. 1. Photograph of first copper-oxide rectifier.

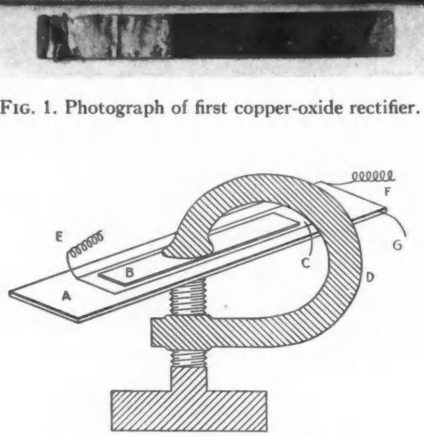

FIG. 2. First experimental assembly.

copper in a furnace at a high temperature, the oxidation being stopped before all the copper was consumed. The mother copper that remained could be used for a support and for a contact on one side. Moreover, the light-sensitive material would have a large area and a very short path through the material in the direction in which the current was expected to flow; namely, from the mother copper through the oxide and into an outside contact.

The decision to use this construction was one fortunate step in the experiment. After a strip of copper had been partially oxidized and a contact applied to it, it was inserted in a Wheatstone bridge in order to determine its effectiveness as a relay by measuring its resistance both in the dark and when illuminated. With the voltages and areas used, the illumination was found to produce no effect, so that from the standpoint of its original purpose, the experiment was a complete failure. For several days many attempts were made to get results by changing various elements of the experiment and it was noticed that while illumination seemed to have no effect on the resistance of the assembly, the resistance indicated by the Wheatstone bridge sometimes was 400 ohms and sometimes, 1200 ohms. This was very puzzling until it was discovered that the resistance depended on which terminal of the bridge was connected to the mother copper and which was connected to the other side of the specimen. A difference in resistance depending on direction of flow seemed to be something entirely new and it at once seemed possible that a unit with such a characteristic might be used as a rectifier. The resistances were very high, but the possibility was there. The original strip of copper is still in existence (Fig. 1). Fig. 2 shows the assembly used, and Fig. 3, the volt-ampere characteristics of the unit as it was determined nine years later when we knew better how to make the test. The structure of the oxide is interesting; it is formed in columns, the bases of which rest in intimate contact with the mother copper (Fig. 4).

Because of the great interest in the original

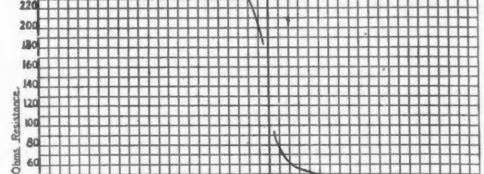

FIG. 3. Characteristics of first copper-oxide rectifier.

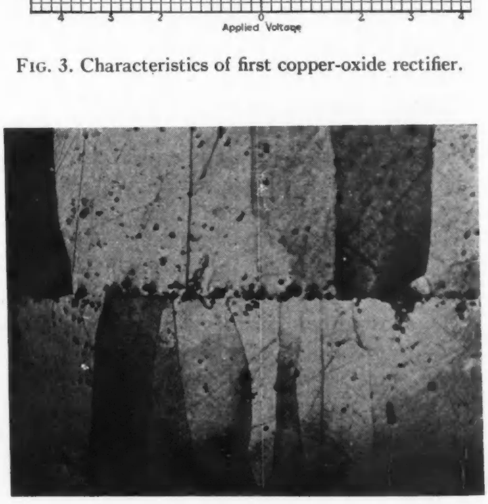

FIG. 4. Cross section of oxide obtained by completely oxidizing a piece of copper, the oxide forming on both sides and resulting in two sets of columns with their bases in contact in the middle of the piece.

problem, the question of the possibility of developing a rectifier had to be set aside. About a year later, in the fall of 1921, the need for a low-capacity rectifier for charging batteries for automatic train control again brought to mind the experience mentioned and the writer suggested that the copper-cuprous-oxide combination might be useful for the purpose. In the experiments then initiated, the first few units constructed were found to have resistances in opposite directions that differed by a factor of 10 approximately, and that was promising. However, the units were erratic and short-lived. This was not strange, since nothing was known about how to use them—at what temperatures they should be operated, the current density that could be used, or the voltages to use on an individual unit. All this had to be gotten by experience and it was soon found that imaginations were not able to go far at a time; it was necessary to pick the way slowly. Within a year, however, a unit had been developed that was thought capable of supplying the desired rectified current. It was not until five years after this that engineers and administrative officials became convinced that the rectifiers were practical. In the meanwhile, hundreds of thousands of experimental units had been made. We had learned how to mount the disks on bolts, obtain a reasonably satisfactory contact, remove the black oxide, oxidize and heat treat the units before assembly, apply the pressure so that it would be maintained, and select the copper that was most satisfactory for the purpose. One particular kind of copper was found to be better than any other and it still is being used. It had been learned roughly what voltage the units would stand, what currents could be used for a given area.

All this was very interesting because the field was entirely uncharted. Consider, for instance, the almost infinite number of possible methods for oxidizing and heat treating a rectifier disk. It was learned that oxidation should take place between 1000°C and the melting point of copper, that better results were obtained if the units were cooled from that temperature down to about 500°C in another furnace, and Dr. P. H. Geiger found that from this furnace it was profitable to quench the units in water. One would think that this would crack the oxide and that mechanically such treatment would destroy the unit. Yet the quench was definitely beneficial for some types of disks.

The progress of the work is indicated by the fact that after about eight years of effort, ratios between reverse and forward resistances at 2 volts had been increased to as much as 130,000 to 1. It is now common in a 1.5-in. disk to have, for 2 volts, 0.3 ohm in the low-resistance direction, and 10,000 ohms in the high-resistance direction. At the beginning such results were not even imagined and they were reached only after a vast amount of cutting and trying which was encouraged by the fact that every additional improvement suggested new uses for the device, another fortunate circumstance that is not

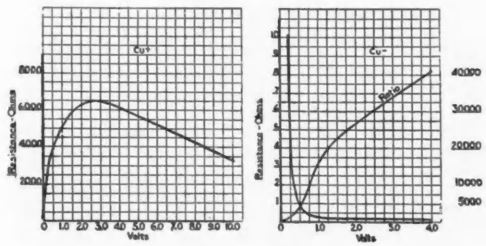

FIG. 5. Characteristics of a standard rectifier.

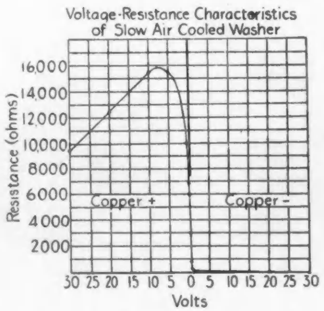

FIG. 6. Characteristics of air-cooled rectifier.

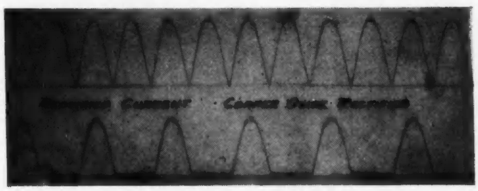

FIG. 7. Rectified wave forms.

always present. As the experimentation went on, many things were learned about the life of the unit, methods of applying ventilation, both natural and forced, and how to match the units to various types of circuits.

It is interesting to compare the characteristic curve for the original unit (Fig. 3) with those for recent types. In Fig. 5 it will be noted that the ratios are enormously greater than they were in the first unit and that the ratio between the resistances in the two different directions is so great that the possible current in the high resistance direction is negligible. It was found that a great number of types of rectifiers could be built, depending on the heat treatment, and that the type could be varied according to the use to which it was to be put. If a rectifier for large currents was wanted, it was made from units with the characteristics shown in Fig. 5. If the currents were to be small but at high voltages, it was made from disks with characteristics similar to those shown in Fig. 6, in which the resistances are much higher. The low-resistance units shown can be used at about 5 volts per disk continuously and the high resistance units will operate satisfactorily at 25 volts per disk in the high resistance direction.

The characteristics of the copper-oxide disks as rectifiers are shown in Fig. 7, in which the upper oscillogram represents the output of a full-wave rectifier and the lower one that of a half-wave rectifier. Note that there is very little distortion. Figs. 8 to 11 show various types of rectifiers and circuits.

Applications

The copper-oxide rectifier may be used to produce a direct current for any one of a vast number of purposes. In fact, new applications are still being found, although among the companies manufacturing the rectifier there must be at least two thousand different designs now available. One of its first uses was for battery charging (Fig. 12, lower right). At that time the a.c. tube had not found its place in the radio industry and vacuum tube filaments had to be heated by direct current from a secondary battery. Often the battery was sold with a charger, or a separate charger was provided. During the radio season of 1926, Westinghouse manufactured six thousand of these chargers a day. In Europe the rectifier was used extensively not only for charging filament batteries, but as substitutes for filament and plate batteries in radio receiving sets. They are still being used to some extent in this field.

Where only an alternating current is available, a copper-oxide rectifier is interposed between the line and a d.c. motor or between a transformer and the motor (Fig. 12); this is done especially in railway signaling. A.c. motors require d.c. fields and it has been found practicable in many cases to supply them from the a.c. lines by way of a copper-oxide rectifier. In signaling, and elsewhere, d.c. relays and electromagnets of all kinds are energized from a.c. circuits through copper-oxide rectifiers or rectifiers and transformers (Fig. 12). When it is desired to polarize a relay or a circuit for any purpose, a one-way rectifier built from copper-oxide units may be used.

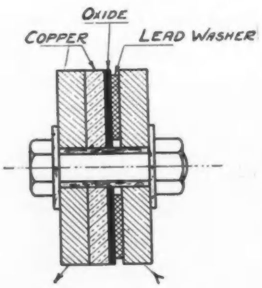

Fig. 8. Section of simplest type of half-wave rectifier.

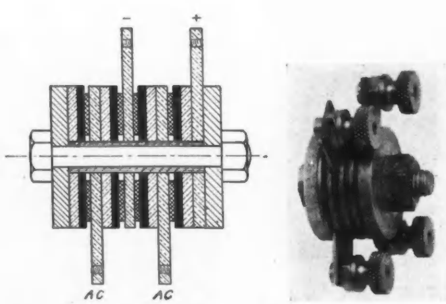

Fig. 9. Four-disk full-wave rectifiers of the same type.

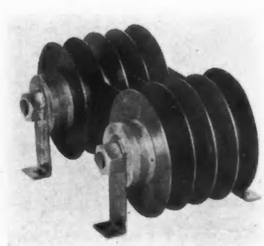

Fig. 10. Rectifier with ventilating fins.

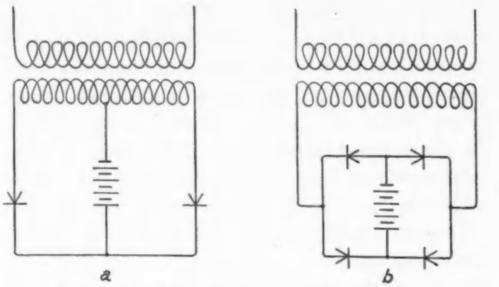

FIG. 11. Circuits for full-wave rectification.

A circuit so polarized can be used to operate a relay or other electromagnet, also polarized by means of rectifiers.

The fields of motors and generators, as well as large electromagnets of any other type, have very high inductances and it is often a problem to open the circuit without damaging the switch

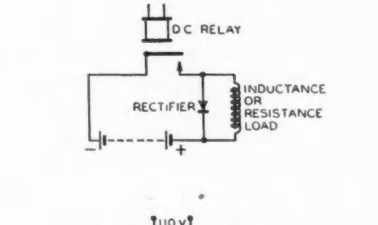

FIG. 12. Various applications.

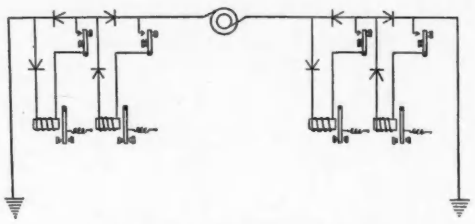

FIG. 13. Circuit for duplex telegraphy.

or even the winding. This difficulty can be avoided by interposing a copper-oxide rectifier as a spark arrester connected in parallel with the field coil in such a direction that its high resistance opposes the voltage normally applied (Fig. 12). When the circuit is opened, the discharge which often produces a damaging spark can then take place through the rectifier in the low resistance direction.

The drop in resistance characteristic in the low resistance direction has made it possible to use rectifier disks for noise suppression in telephone lines. This is done extensively in Europe and to some extent in this country. The assembly of rectifier disks used is such that the normal voltages applied to a telephone receiver will not leak appreciably across the rectifier which is connected so that the voltage is applied in the low resistance direction; that is, the voltage is comparatively low, so that the rectifier resistance is high. When a shock of some kind is applied to the line, the voltage is comparatively high, with the result that the rectifier constitutes a low

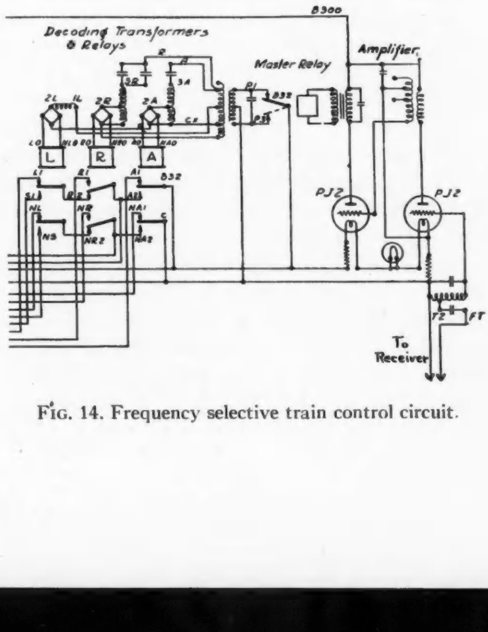

FIG. 14. Frequency selective train control circuit.

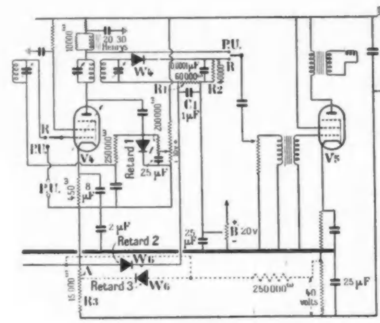

Fig. 15. Radio receiver circuit.

resistance shunt across the receiving instrument and therefore takes the energy of the shock.

The polarizing effect can be used to duplex a telegraph line, as shown in Fig. 13.

In a frequency-selective train control circuit (Fig. 14) the rectifier is used between the tuned circuits and d.c. relays. The d.c. relays require relatively small power and the rectifiers have a low impedance; thus, the power required for the relay can be taken from a tuned circuit without loading it sufficiently to destroy the required sharpness of tuning. Since the rectifier is easily matched to a small part of the tuned circuit and can at the same time be matched to an efficient relay, it is a valuable auxiliary in such a selective circuit.

In France and England the rectifier has been used extensively in radio receiver circuits. In Fig. 15 the copper-oxide rectifier is used for detection, volume control, and supply of d.c. plate voltages. The units used are very small, the disks having been made in sizes as small as 0.030 in. in diameter. A typical assembly is shown in Fig. 16. Hundreds of thousands have been used in such applications. The detectors can be used for modulators, as well as for demodulators. Several years ago when the Bell Telephone Laboratories set up a demonstration apparatus to transmit a concert of the Philadelphia Orchestra from Philadelphia to Washington, copper-oxide rectifiers were used as modulators. Those who carried out the experiment stated that greater purity of tone was obtained by their use than by any other available means.

In the other extreme, the copper-oxide rectifier has been used for electrochemical work, especially in plating metal parts for automobiles and bicycles. The largest unit of this type known to the writer is capable of delivering 12,000 amp. at 5–8 volts (Fig. 17). The rectifier plates are 15×3 in. and are oxidized on both sides. A real problem in the design of this rectifier was to place the bus bars so as to reduce power losses and the electromagnetic forces between the heavy copper strips.

The unidirectional resistance characteristic has made it possible to use the rectifiers as leaks to prevent electrolysis of buried conduits or water pipes. One interesting application based on the same characteristic was made at one of the Westinghouse laboratories. The unit was attached to an oscillograph which was used for recording an asymmetric wave so that the high resistance was in series on the high side of the wave and the low resistance was in series on the low side of the wave, thereby enabling the instrument to record a readable amplitude for both portions.

Another application in which very low current and high voltage is used is in smoke and dust consumers and in connection with x-ray apparatus. These units have been built up to 200,000 v.

Of interest to all experimentalists is the use of the rectifier as a part of a.c. instruments. A.c. voltmeters have low resistances and therefore cannot be used in circuits of limited power. When a copper-oxide rectifier is interposed in a circuit of a d'Arsonval instrument, the instrument can be used for measuring alternating currents and voltages and it is possible for the voltmeter to have 2000 ohm/v if desired, which gives a better condition even than is usually available for d.c. circuits. Such instruments are convenient and flexible and can be used to measure any alternating current and voltage.

In these various applications, and the illustrations might be carried on very much farther, units have been described that carry currents from less than 10^{-7} up to 12,000 amp., or a ratio of 10^{11}. The same ratio exists between the largest and smallest voltages that can be rectified. In power, rectifiers range from 10^{-14} w to 100 kw

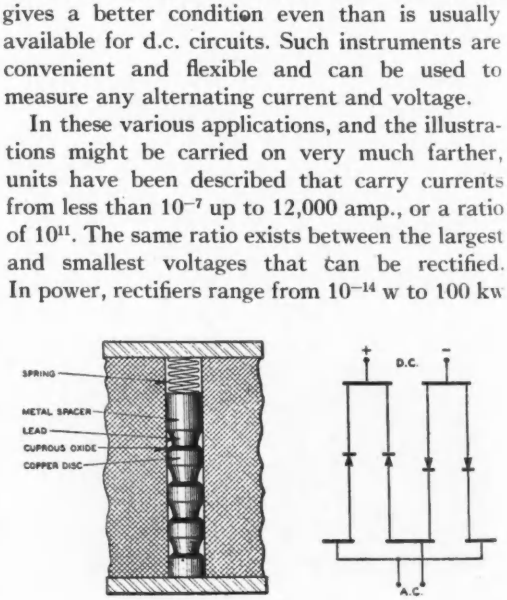

Fig. 16. A radio detector.

with a ratio between these extremes of 10^{19}. It is unusual in a single type of apparatus to find such a wide range of powers, currents, or voltages, and the performance is made even more striking by the fact that the same efficiencies can be had over the whole range provided the apparatus is matched to the circuit in which it is used. The efficiencies of copper-oxide rectifiers range from 50 to 90 percent. In practical production 60 to 70 percent is easily provided. This is to be contrasted with 1920 when the only small-power rectifiers that were available had efficiencies of 20 percent or less.

One day during our early experience with copper-oxide rectifiers a small unit was being used with a d'Arsonval meter to measure 10,000-cycle current in an experiment in progress in the yard of our plant. Those who were using the instrument found that the indications were erratic and they blamed this on the rectifier, since it was the new part of the circuit. Experience had not indicated that the rectifier should show such behavior and the writer therefore made an investigation. It was soon noted that the variations were between rather definite limits and that one of the readings was obtained when the shadow of an operator fell on the unit and the other, when the sun was allowed to shine on it. This was the first indication of a photoelectric effect in a copper-oxide rectifier, and a further study of the effect by Dr. Geiger and the writer showed that it was due to the production of an electromotive force at the

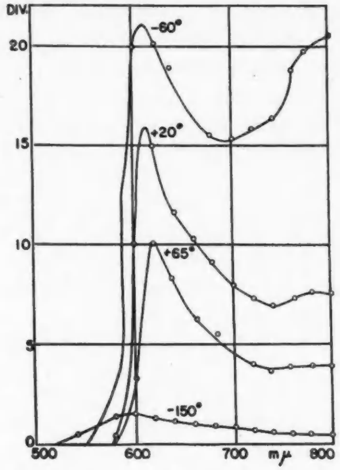

FIG. 18. Spectral sensitivity curve for back-wall photoelectric cell. [From a paper by Lange.]

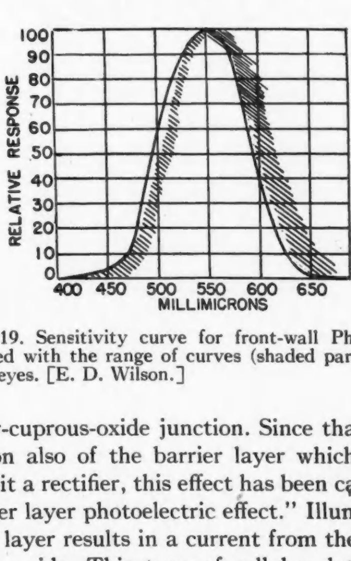

FIG. 19. Sensitivity curve for front-wall Photox cell compared with the range of curves (shaded part) of 125 human eyes. [E. D. Wilson.]

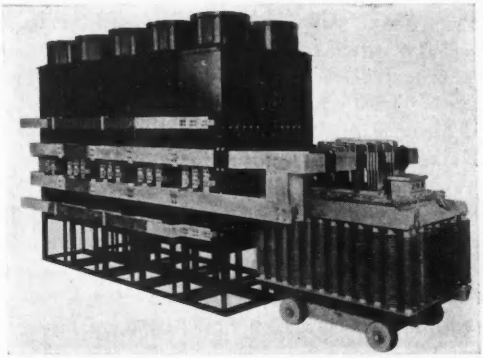

FIG. 17. This electroplating unit is over 8 ft. high and consists of 10 columns of rectifiers. The cylinder at the top of each column houses a fan for ventilating the plates in the column. The truck contains the transformer.

copper-cuprous-oxide junction. Since that is the location also of the barrier layer which makes the unit a rectifier, this effect has been called the "barrier layer photoelectric effect." Illumination of the layer results in a current from the copper to the oxide. This type of cell has later been called, by Schottky, a "back-wall photoelectric cell." It has the characteristic that the sensitivity exists only in the red part of the spectrum because the cuprous oxide is not transparent to the shorter wave-lengths (Fig. 18).

During the years immediately following this discovery, Schottky and Lange in Germany developed what they later called the "front-wall photoelectric cell," which is constructed by oxidizing a piece of copper in the same way as

for a back-wall cell or rectifier and then depositing on the free surface of the cuprous oxide, usually by cathode sputtering, a semitransparent layer of metal. When the unit is illuminated through the semitransparent metal, an electromotive force is produced here also from the metal to the oxide. Since the light in this case does not have to pass through a thick layer of oxide, the over-all sensitivity of the cell is larger and extends farther into the blue portion of the spectrum. With the front-wall cell a spectral sensitivity curve which corresponds very closely to that for the human eye is obtained (Fig. 19). The power output of such a unit in a matched circuit is of the order of 7 μw/in.^{2} with an illumination of 50 ft. *ca.* The details in the explanation of this photoelectric phenomenon are complicated and it suffices to say that it is the result of the diffusion across the barrier layer of electrons that are liberated in the internal photoelectric effect in the semi-conductor, cuprous oxide.

Everyone will agree with the assertion made at the beginning of this paper—that fortune may have had as much to do with these developments as the intensive and long-continued investigations which are still in progress. It should be pointed out, too, that the rectifier and the photocell are by-products and the only important positive results of the original investigation.

The University of Wisconsin Physical Museum

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THE Wisconsin Physics Museum was started eighteen years ago, and was believed at the time to be the only one of the sort in the country. In spite of its small size compared with some of the newer museums, the interest it has aroused, coupled with the general growth of the museum idea, the fact that we in this department regard it as a considerable instructional asset, and the relatively long experience we have had in running such a museum, seems to justify its description.[1]

The museum occupies a room 14×20 ft. on one side of a main corridor in our physical laboratory and separated from this hall by a glazed partition. It houses some eighty exhibits, the general nature of which is evident from Figs. 1 and 2. It is also clear that this is about the maximum number which can be accommodated in this space without confusion.

The material on exhibition may be roughly divided into two general classes, of which the first comprises charts, transparencies, wall cases showing manufacturing stages and parts of electrical instruments, etc., some optical apparatus and a number of other still exhibits. Such material requires a minimum of space and upkeep. One of the most interesting and simple optical arrangements is a pair of plane mirrors set at a right angle; in them reflected printed matter is readable and one may—possibly for the first time—"see himself as others see him."

Of much greater interest, however, are the exhibits that "work." These vary in complexity from the cut-away push-button-operated Ford motor, transmission, and differential, to the simple air pressure experiments shown in Fig. 2 (left). The conservation-of-angular-momentum rotating platform (Fig. 1, left center) is always a center of interest. Some good modifications of the usual demonstrations—including the principle of the gyrocompass—can be shown when a weighted bicycle wheel is used in connection with this turntable. The wheel can also be used to demonstrate the principles of the gyroscope. In addition, a large electrically driven gyroscope in a box (Fig. 1, left) with which one can "wrestle" provides a striking illustration of gyroscopic reactions.

A Foucault pendulum (Fig. 1, rear center) which is 1440 cm long and occupies a special well, swings over a card graduated in hours for our latitude. It is started every morning at 8 o'clock and for the rest of the day gives the time within a few minutes. It is accompanied by a small rotating table of the usual demonstration type with a miniature Foucault pendulum. A working Flettner rotor ship model (Fig. 2, rear center), ball on air jet, and collection of glass pumps give an

[1] A short article on it appeared in Science **54**, 548 (1921).

insight into certain features of the statics and dynamics of fluids. Most of the working exhibits are in the fields of mechanics, heat, electricity and magnetism; but sound is not overlooked, for there is an experiment on absorption (Fig. 2, left) and a demonstration on binaural perception of direction (Fig. 1, left center).

Some of our best exhibits have been gifts from manufacturers. It must not be concluded that automobile and apparatus makers are merely waiting to be asked to contribute expensive demonstration pieces, but it is probable that any similar museum which has been in successful operation for a number of years and thereby has acquired some standing would be accorded the same courteous treatment in this respect that we have experienced.

The museum occupies an important place in our instructional scheme. In connection with his general physical laboratory work every student is asked to study certain things here. Early in the course he is required to experiment with the probability board (Fig. 1, extreme right) to get some idea, at least, of what is meant by a probability curve. Later he times the Foucault pendulum and computes its length, makes experiments with eddy currents and other magnetic effects, including the thermo-magnet, observes the spectrum of the mercury lamp, and performs certain other experiments.

Lecturers in the several elementary courses not infrequently make use of material from the museum in their demonstrations. The student is then asked to repeat the experiment in the museum and investigate its possibilities thoroughly. Instructors also refer their classes to the museum for certain demonstrations, for example, the Cavendish balance (mounted high on the wall, not shown), whose use in lecture requires an abnormal amount of preparation and demonstration time. And what student, of any ambition at all, would not rather shift the attracting spheres himself and see gravitation deflect the torsion pendulum, than merely watch a lecturer do it?

All exhibits are accompanied by written explanations which aim at making the fundamental

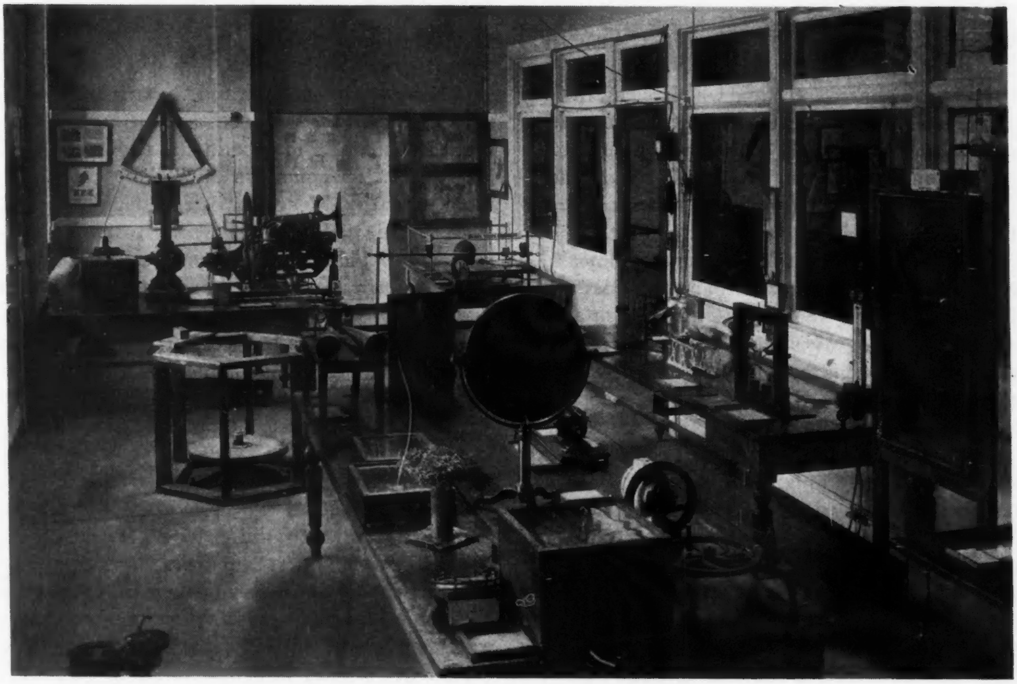

FIG. 1. Physics museum, looking south.

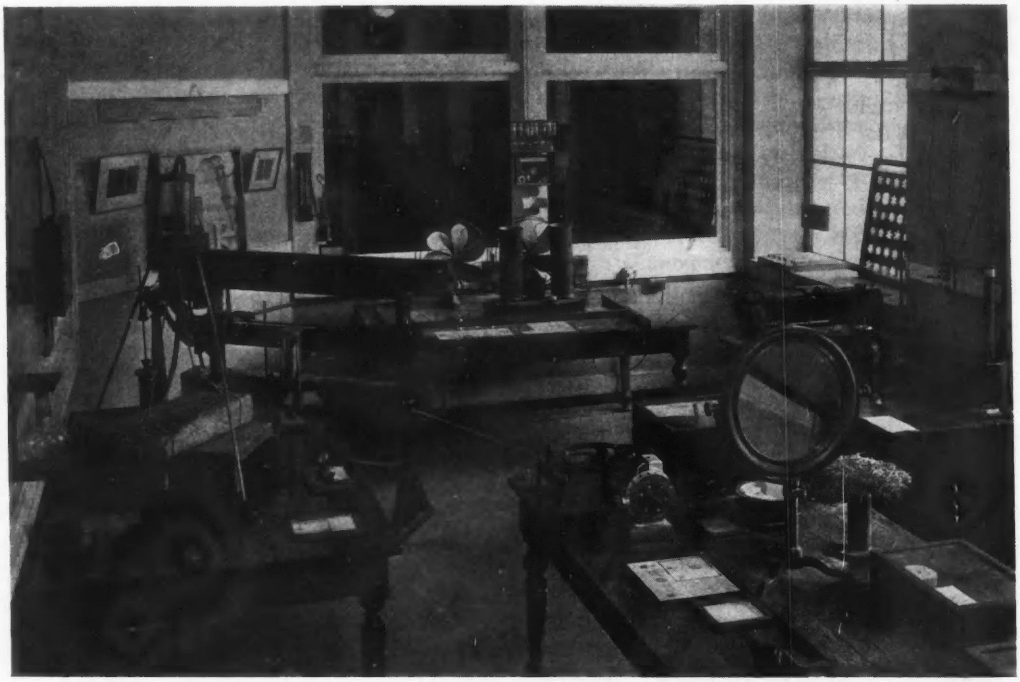

FIG. 2. Physics museum, looking north.

principles clear, even to one who has had little or no physics. A few of the descriptions are rather elaborate. With the aid of the one for the Cavendish balance the student who is so minded actually can determine roughly the constant of gravitation and thereby the mass of the earth.

The museum is open for five hours a day and is entirely without the services of an attendant save for a few hours a week of attention from an apparatus man or assistant. The room rarely is empty and not infrequently is crowded. While most of the users are students, townspeople are frequent visitors as well. So far (here we pause to take the customary precautions!) there has been no vandalism and almost no thievery. Breakage has cost only a few dollars a year for replacement. At times the small boy has threatened to become a problem, but only rarely do we have to limit his vigorous experimental activities. Sometimes it has seemed as if wood and metal could not resist the onslaught to which the turn table, loop-the-loop, repulsion-induction rings, or electromagnet is subjected; but after the fray is over everything still seems to be in place and the care with which switches have been opened tends to restore one's faith in humanity in general and the small boy in particular. The museum is by way of being a small scientific Mecca for science classes of local high schools and those of nearby towns.

It is our belief that the physics museum has come to stay as a definite and important aid in the teaching of physics and in stimulating interest in the subject. We also feel that any department which in the future plans a new laboratory without including arrangements for such a museum will eventually regret the omission. But lack of suitable space at this time need not deter any department from immediately starting such a collection on a small scale. A corner of a corridor and a little apparatus drawn from the demonstration collection—or, still better, made especially for the purpose—will serve as a good beginning; and if it is changed occasionally the interest in it will keep up indefinitely. Such a start is now being made in more than one college or university in this country.

Elementary Problems Illustrating the Computation of Charge Distribution, Potential and Capacitance of Conductors

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STUDENTS of elementary physics are often misguided by the non-uniform distribution of charge on a conductor of irregular shape into a feeling that the potential is not uniform throughout the conductor. Treatments in advanced texts have the advantage that the uniformity of potential throughout a conductor is kept constantly before the student, for it is used as one of the fundamental (boundary) conditions which the solution of the electrostatic problem must satisfy. Thus electrostatic charge distributions in conductors are found from a knowledge of the total charge, together with the rule for computing the potential at a point as the summation (over all charges) of the charge divided by the distance to that point.[1] The actual distribution of charge is the one required to maintain all parts of the conductor at the same potential.

These concepts are sufficiently simple to justify their discussion in an elementary course. Although they have rarely been mentioned in texts for use in liberal arts courses, they have been discussed qualitatively in a number of elementary physics texts intended for the use of engineering students.

Even in texts where the principles are adequately discussed they are not emphasized by suitably chosen numerical problems. The wide use of problems in physics teaching would suggest that they have been found helpful in establishing a working knowledge of principles, and hence also should be useful here. The primary purpose of this paper is to suggest types of numerical problems that can be solved by elementary students through a direct use of the foregoing principles.

One type of problem most easily solved by direct use of the principle that the potential throughout a conductor is constant, concerns the distribution of charge among connected conducting spheres. The center of one sphere may be chosen as the point for which the potential is computed, and then, since the charge on any sphere is located on its surface, the q/r-contribution from the charge on this sphere is accurately the charge on the sphere divided by its radius. The contributions of the charges on all other spheres to the potential at the center of the chosen sphere, may be found quite easily with desired accuracy. In the problems which follow it is sufficient to assume that the effect is the same as if the charge on each of these other spheres were concentrated at its center.[2]

As a first illustration take the problem of finding how a charge of Q statcoulombs will be divided between two, connected, conducting spheres, each 10.00 cm in radius and placed with their centers 50.00 cm apart. The connecting wire is so fine that the charge upon it may be neglected. The potential of the system and its capacitance are obtained from the charge distribution.

Call q_1 the charge on the first sphere and q_2 that on the second. Then if the asymmetry of the charge on either sphere due to the presence of the other be neglected, it is easy to compute the potential at the center of either sphere. The actual distribution of charge is the one required to bring the two spheres to the same potential V_s. Thus computing the potential at the center of sphere 1, we write $V_s=(q_1/10)+(q_2/50)$. Similarly for the potential at the center of sphere 2, we write $V_s=(q_2/10)+(q_1/50)$. The symmetry of these equations, which of course comes directly from the symmetry of the geometry, shows that q_1 equals q_2; and since the total charge on the two spheres is Q, we find that the charge on either sphere is $Q/2$. The capacitance of the system may be computed from the definition of capacitance.

[1] Mason and Weaver, *Electromagnetic Field* (Chicago, 1929), Sec. 21, p. 91.

[2] Actually, of course, the charge on a sphere is apt to be asymmetrical because of the presence of other charges. The contribution of the charge on a given sphere to the potential at points outside it is then: (1) a part due to the total charge on the sphere considered concentrated at its center plus (2) a part due to a dipole of certain strength. The asymmetry of the charge distribution over the surface of a sphere does not alter the computation of the potential at its center. The polarization of charge on distant spheres does alter the potential somewhat, but the effect is small, for (a) the asymmetry itself is small, and the equivalent dipole is weak, and (b) the contribution of a dipole to electrostatic potential is small, and it decreases as the inverse second power of the distance.

Thus we find[3] $C=Q/V_s=Q/\{(Q/20)+(Q/100)\}=16.67$ cm.

The fact that the charge is divided equally between the two spheres might well have been taken directly from the statement of the problem, since there is nothing in the data to distinguish one of the spheres from the other. If a problem is desired for which the answer is less obvious, either an external point charge may be introduced closer to one of the spheres than it is to the other, or the spheres may be made different in size. Hereafter, if spheres are indistinguishable in the physical arrangement, the equality of charge upon them will be taken directly to save labor.

The problem in which the two, connected spheres differ in size is instructive. Suppose that one of the spheres in the previous problem is made 1 cm in radius. Letting q be the charge on the larger sphere and q' be that on the smaller sphere, we may write for the potential at the center of the larger sphere, $V_s=(q/10)+(q'/50)$. Similarly, for the center of the smaller sphere, $V_s=(q'/1)+(q/50)$. Since the total charge is Q, the foregoing equations give $q=98Q/106$ and $q'=8Q/106$. Analysis of these results shows that the average surface density of charge on the smaller sphere is more than eight times that on the larger. This illustrates the increased surface density of charge on small projections of conducting systems. At the same time, the computations involved in the solution of the problem make the cause of this concentration apparent. The potential of the system turns out to be about $Q/10.8$ statvolts, and the capacitance therefore is 10.8 cm.

A third problem may be made from the first by placing a third similar sphere in line with the first two and at a distance (measured from center to center) of 50.0 cm from the nearer one. Now since there is nothing to distinguish the end spheres from each other, their charges will be equal, say q. Let the charge of the middle sphere be q'. The potential V_s at the center of the middle sphere is $V_s=(2q/50)+(q'/10)$. Similarly for the center of either end sphere, the potential is $V_s=(q/10)+(q'/50)+(q/100)$. Then q is $8Q/23$ and q' is $7Q/23$. The potential of the system is $Q/22.55$ statvolts, and its capacitance, 22.55 cm.

If the problem is changed to one in which similar spheres 10.00 cm in radius appear at the corners of a square 70.7 cm on each side and a fifth sphere is at the center of the square, we may obtain a solution by exactly the same methods. If Q is the total charge, q' is the charge on the center sphere, and q is the charge on each of the corner spheres, then q is $0.2115Q$ statcoulombs, and q' is $0.1541Q$ statcoulombs. The potential of the system is $Q/30.93$ statvolts and its capacitance, 30.93 cm.

Finally consider spheres 10.00 cm in radius placed at each of the six corners of an octahedron 70.7 cm on each edge, with a seventh similar sphere placed at the center. If q' be the charge in statcoulombs on the center sphere and q that on each of the corner spheres, then q is $0.152Q$ and q', $0.088Q$ statcoulombs. The potential is $Q/36.94$ statvolts and the capitance, 36.94 cm.

A problem of a slightly different type solvable by the same principles is that of determining the difference of potential between two similar, unconnected spheres resulting from the transfer of a charge of Q statcoulombs from the one to the other. The problem is of special interest because it represents, in simplified form, the electrostatics of the Van de Graaff generator. Consider two conducting spheres each 2.00 m in radius placed with their centers 10.00 m apart. Then the potential of the first sphere is $V_1=(Q/200)-(Q/1000)=0.00400Q$ statvolts and that of the second is the negative of this expression. The potential difference between the spheres is $0.00800Q$. The capacitance between the spheres is[4] 125.0 cm.

Exercises of the type presented here are well suited to the teaching of elementary physics, for the following reasons.

1. The emphasis is on physical principles. The only mathematics used is elementary algebra. The defining characteristic of a conductor is the principle underlying the computation. Furthermore the sequence of problems presented here illustrates several of the more important facts concerning charges on conducting systems: (*a*) the charge is most concentrated on the outer parts of conducting systems and the surface density of charge is greatest on the smallest projections of conductors; (*b*) since

[3] Through an application of the method of images, it is possible to correct this computation for the asymmetry of charge on a single sphere. See Reference 1, pp. 112–113 or Page and Adams, *Principles of Electricity* (Van Nostrand, 1931), pp. 101–106. The result obtained in this way is 16.69 cm. The approximation obtained by neglecting the asymmetry of charge is indeed close.

[4] Correcting for the asymmetry of the charge, the result is 125.2 cm.

the potential of a given conductor is raised or lowered by other charges in the vicinity, the capacitance of a connected conducting system is less than the sum of the capacitances of the parts considered as isolated units.

2. The computations involved constitute useful approximations to the solution of actual problems. The answers obtained are definite and not conspicuously incomplete even though by advanced methods more detailed information may be obtained. The approximations obtained by elementary methods are adequate for most practical numerical work.

3. Such types of problems are an aid in sustaining class interest. They provide a great variety of physical problems involving the same elementary mathematical skills. The electrostatics of the Van de Graaff generator is associated naturally with an important recent development.

In conclusion, it should be emphasized that the relations existing among the fundamental electrostatic quantities—charge, potential and field strength—are essentially simple. In a basic course, they should be discussed and emphasized by numerical examples. The problems discussed in this paper involve the relationship between charge and potential, and they illustrate the principles underlying the distribution of charge on conductors. Both the direct applicability of fundamental physical principles and the absence of difficult mathematics recommend them for use.

Can College Physics Be Popularized?

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THERE is great need for some constructive thinking about our methods of teaching physics. If our methods and accomplishments are all that they should be we at least can satisfy our minds as to that fact. If we are failing to accomplish all that reasonably could be expected of us as teachers, the part of wisdom is to find the causes of our failure and attempt to correct them.

This discussion is based upon the following seven considerations. Supporting data are largely omitted.

1. From recent surveys it appears that there are almost three times as many college students pursuing chemistry as physics. There are eight students majoring in chemistry to one in physics. In a survey made last fall Professor John B. Daffin of Mary Baldwin College found that in thirty-three women's colleges having a total attendance of 22,069, the enrollments in the first courses in physics, chemistry and biology were in the ratios 1 : 2 : 3, and the ratios for majors were 1 : 6 : 10. If the results of various surveys are to be trusted, there are large groups of students who pass through our whole educational system, from the kindergarten to the graduate school, with little or no direct contact with physics as an academic subject. Under these conditions it seems almost paradoxical to assert that physics has ranked in the past, and can rank to a greater extent in the future, with the school and college subjects of greatest cultural value.

2. These conditions revealed by surveys exist despite the generally recognized fact that physics is one of the most basic of the sciences. This is not to say that physics necessarily is the most interesting, most valuable or most practical science for the greatest number of students but that it enters basically into all the common sciences more than any other single science.

3. Physics as a basic science touches our daily lives at almost every turn we make. It is a very practical science.

4. Along with other educators I believe that each general subject pursued by a student should contribute to good citizenship. Physics should occupy no minor position in this important function. When given a chance, it can make profound contributions to our political, industrial, social and spiritual lives.

5. Physics has in the past, and can in the future, contribute immensely to advances in civilization and in social conditions and standards. A multitude of illustrations could be cited. A single one will be mentioned here.

When Edison, in his early work with the incandescent lamp, observed and recorded in his notebook what is now called the Edison effect, he did not realize the importance of his discovery to

pure physics. This is evident from the fact that it was put aside as a notebook observation for a number of years. About 1900, however, this discovery was made the basis of what is now an amazingly diversified family of vacuum tubes which affects our lives at every turn. It is almost beyond the power of the imagination to conceive the extent to which the Edison effect has contributed to our mastery over nature, and to our industrial, social and intellectual progress. In addition to this, thousands of individuals are gainfully employed in manufacturing, distributing and using the products that have developed out of it.

The lack of popularity of physics as an academic subject cannot reasonably be charged to the science itself. I fail to see anything intrinsic in physics that should cause students to turn from it. On the other hand I see an extraordinary amount in it to appeal to their curiosity. Physical nature is all about us, and within us. It is beyond us with all its enticing mystery to the outermost bounds of space. It is in the rain and the snow and the lightning flash, in the sunrise tints and gorgeous evening sunset glows, in the warming sun rays of springtime. Mention all the elements of the related sciences that appeal to the mind of youth and they will be found also in the realm of physics. The passionate urge in childhood and youth to "see the wheels go round" is indelibly stamped upon us.

When all due allowances are made for some of the oft quoted causes given for the subordinate position occupied by physics as an academic subject, there appears to remain some more basic or fundamental cause for the situation. In seeking for this cause, possibly we can find a clue in literature. Shakespeare, when the minor position of Brutus to Caesar is under consideration, causes Cassius to say to Brutus, "The fault, dear Brutus, is not in our stars but in ourselves that we are underlings." The most vital factor in the popularity of physics among college students is not an external one but is internal and is connected with our methods of teaching the subject.

In finding a solution it is convenient to regard our problem from three viewpoints: lecture, quiz and experiment. For lack of space we shall confine our discussion of the first two viewpoints to a single remark about each. Lectures in physics should be, and often are, stimulating to the interest and conducive to good thinking. As for the average quiz period, if the reactions of students who attend them and instructors who conduct them are to be measures of their effectiveness, then they can be stamped as depressive and as largely void of interest-producing elements.

The history of physics practically establishes the place and function of experimental physics in popularizing the subject. History reveals that no great amount of interest was manifest in the subject of physics from the time of the Greek philosophers to the time of Galileo and Newton. This period was almost void of questions put directly to nature. When curiosity as to nature's way of working arose the question was asked, "What did Plato or Aristotle say about it?" What do the books say about it? Seldom did one attempt to answer a question by an experiment, or think to let nature interpret itself. The sparks of interest created by Galileo and Newton were due to their experimental work and not to reading Greek textbooks. In saying this I am not unmindful of the fact that Newton is considered to have been a mathematical physicist.

The next glow of interest in physics is associated with the opening to college students of experimental work in physics in Berlin by Magnus in 1845 and probably in the same year at Glasgow by Kelvin. The awakening of interest in America came with introduction of experimental work in the Massachusetts Institute of Technology, Harvard, Cornell, Rensselaer, and a few other institutions. This was in the 1870 decade. A flood of interest and flocking of students into secondary school classes in physics was brought about by Alfred P. Gage in the Boston High School about 1880. This interest was greatly amplified and extended over the whole country when Gage published his *Introduction to Physics* and *Elements of Physics* in 1888.

J. J. Thomson in *The History of the Cavendish Laboratory*, attributes to the experimental work at Cambridge excellent results in creating interest in the subject of physics.

Another wave of popular interest in physics was created by Robert A. Millikan when he established the experimental courses at the University of Chicago soon after the establishment of that institution. This work was widely dis-

seminated by the publication of the experimental texts, *Mechanics*, *Molecular Physics and Heat* and *Electricity, Sound and Light*. Like conditions were manifest in secondary education when Millikan and Gale introduced into the University of Chicago High School their *First Course in Physics*, which was accompanied by a complete laboratory course. It is interesting to note that one complete set of apparatus for this laboratory course could be purchased as late as 1916 at a cost of $52.76.

The period from the discovery of x-rays in 1895 to the present date has been one of the most interesting and spectacular in the whole history of physics. The quickened interest in the subject has not been confined to the physicists alone. It has spread into the other sciences and to large numbers of the laity. The fruitfulness in interest and achievement of this forty-one year interval was not attained by reading textbooks on physics and philosophy. The secret lies in experimental research. The history of physics reveals that the most potent element in building up a living spirit in physics is the experimental and research aspect.

Physics once was a popular college subject. It can be made so again. In conclusion, I can express an opinion, and it is worth only what an opinion is worth: one of our difficulties is that we teach physics too much as a fact-getting, textbook subject. I quote from three great educators, two of them physicists. Professor Agassiz told his students and prospective teachers "that the way to master ichthyology is to study a fish instead of studying about a fish." Professor Gage said something which I believe has great wisdom in it: "To the pupil,—'Read nature in the language of an experiment. That is, put your question, when possible, to nature rather than to persons. Teachers and books may guide you as to the best method of procedure, but your own hands, eyes, and intellect must acquire knowledge directly from nature if you would really know.' " Professor Foley in the preface to his recent *College Physics* gives utterance to most challenging and stimulating principles as follows:

"This text has been prepared in the belief that the chief function of a physics teacher, or a textbook, is not to impart facts, but to arouse and maintain a keen interest in physical phenomena. Students who learn facts only, with little or no curiosity about their mutual relationships and interdependence, forget most of what they acquire in far less time than it took to learn it. Physics, primarily, should be the development of a scientific method of reasoning, hence the student should learn to think."

As my part in such a program I am trying to determine the value of experimental studies and projects as interest-producing principles in elementary college physics. Some work has already been done but the results thus far accumulated are not sufficient to justify reporting them.

Cooperation with Science Service

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The Origin of the Horsepower Unit

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JAMES WATT invented his steam engine in 1765, but it was not until about 1776 that he produced an engine that satisfied him. His first engines, like those of Savery and Newcomen, were used for pumping water from mines. However, with the introduction of the rotary engine about 1780, Watt found it necessary to have a unit with which to rate his engines which were to replace water and horse mills. The fact that horses were commonly used to furnish the motive power for mills probably led him to rate the engines in terms of horses.

Watt was, nevertheless, certainly not the first to think of rating an engine in terms of horses, for we find in *The Miner's Friend*[1] the statement:

"I have only this to urge that water in its fall from any determinate height has simply a force answerable and equal to the force that raises it. So that an engine which will raise as much water as two horses working together at one time in such a work can do, and for which there must be constantly kept ten or twelve horses for doing the same, then I say such an engine will do the work or labour of ten or twelve horses."

It is quite clear from this statement that Savery was not thinking of the specific rate at which one horse works.

Some years later Desaguliers[2] says:

"An horse draws with the greatest advantage, . . . when the line of direction . . . is level with the horse's breast, and is able in such a situation to draw 200 lb. eight hours a day, and walking about two mile and a half an hour . . . but so much as an horse could draw up out of a well over a single pulley or roller (made to have as little friction as possible) is properly what an horse can draw; and horses, one with another draw about 200 lb. in such a case, as we said before."

Presumably Desaguliers did not have in mind that a horse would pull 200 lbs. continuously for eight hours but that roughly for half that time would be returning to the well under no load. A simple computation on this basis shows that Desaguliers rated a horse as capable of doing 44,000 ft.lb./min.

Smeaton,[3] in March 1775, in discussing the Cronstadt engine says in part:

"This will produce 27,300 tons of water in twenty-four hours to the height of 53 feet, and is equal to the labour of 400 horses."

Here we have probably for the first time a numerical comparison between a steam engine and horses. Since Smeaton does not tell us how many of the animals would be in use at one time the figures are of little value.

In 1775 James Watt formed a partnership with Matthew Boulton of Birmingham for the manufacture and sale of steam engines. The first engines were sold principally to the mines in Cornwall. The years 1780 to 1785 found Watt very busy on the problem of converting reciprocating motion into rotation in order to make the steam engine available to mill owners. During this time he kept "Blotting and Calculation" books, wherein he made many notes and calculations from time to time. It is in such a book for the years 1782 and 1783 that we find a record of the steps by which Watt arrived at the unit of horsepower now generally accepted and used. The first reference, found on page two of this book and written in August, 1782, reads in part as follows:

"Mr. Worthington of Manchester wants a mill to grind and rasp logwood and to drive a calender—in power for all which is computed to be about that of 12 horses.

"Mr. Wriggley his millwright says, a mill horse walks in 24 feet dia^{r} and makes 2 ½ turns p. minute.

2 ½ turns = 60 y^{ds} p. minute, say at the rate of 180^{lb} p. horse. . . .

60y^{d} × 3 = 180 feet × 180 pounds = 32400 ÷ 120 feet of pistons motion = 270^{lbs} × by 12 horses = 3240^{lbs} load of cyl^{r} which at 5 lb p. inch = 29 inch cyl^{r}, 6 feet stroke, 20 p. minute."

Here we have Watt's first value for the power of a horse, 32,400 ft.lb./min. That it was calculated rather approximately is obvious upon looking at his figures. Using the same data one can get 33,930 ft.lb./min. Further, nothing is said about how he arrived at the 180-lb. pull exerted by a horse. There is also nothing to indicate he arrived at the value through experiment. It is, moreover, 20 lb. less than the value given by Desaguliers.

[1] Thomas Savery, *The Miner's Friend* (1702), pp. 29–30.
[2] *A Course of Experimental Philosophy*, ed. 3 (1763), Vol. I, p. 251.
[3] *Reports of the Late John Smeaton* (1812), Vol. II, p. 361.

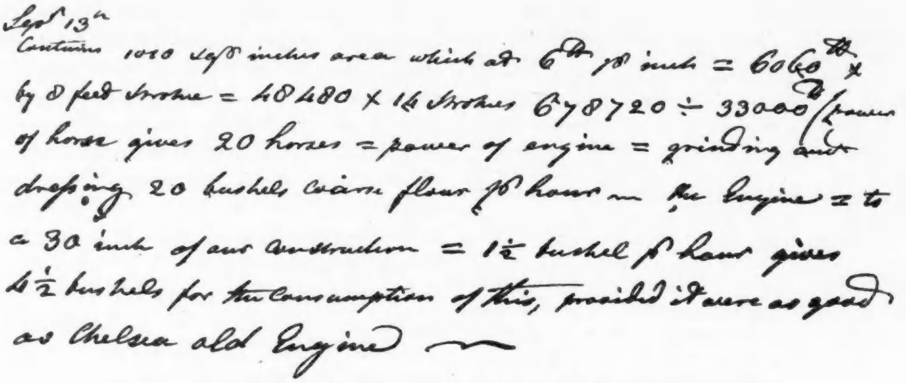
Sep^r 13th
Contains 1010 sq^r inches area which at 6lb p^r inch = 6060lb x by 8 feet stroke = 48480 x 14 strokes 678720 ÷ 33000lb / power of horse gives 20 horses = power of engine = grinding and dressing 20 bushels coarse flour p^r hour — the Engine = to a 30 inch of our construction = 1½ bushel p^r hour gives 4½ bushels for the consumption of this, provided it were as good as Chelsea old Engine —

FIG. 1. Photostat of an entry in Watt's "Blotting and Calculation" book.

The next reference, on page 11 of the same book, reads:

"Mr. Reynolds of Kelley wants an Engine to turn two pair of common mill stones with the common velocity now one pair mill stones is reckoned = to 8 horse, consequently 2 pair = 16 horses, and each horse is = to 180^{lb} moving with a velocity of 3 feet p. ″ consequently 180×3 ×160 = 32400×16 horses. . . ."

From these figures Watt proceeds to compute the proper engine for the task. The interesting point is that here the 32,400 ft.lb. appears for the second time.

Still further in the same book (Fig. 1) under the date of September 13, 1783 we read without any previous explanation:

"contains 1010 sq^{r} inches area which at 6^{lb} p. inch = 6060^{lb} ×by 8 feet stroke = 48480×14 strokes 678720 ÷ 33000^{lb}/ power of horse gives 20 horses = power of engine. . . ."

Thus we have Watt using for the first time 33,000 instead of 32,400. No reason is given, but we may suppose he made the change in order to use a round number. The use of the larger number is natural since it would be to his advantage to underrate rather than overrate his engines. A little later in the same year, 1783, we find the entry:

"Black fryars Corn Mill Engine

Is required to work 18 pair of stones and each pair to grind 6 Bushels p. hour, and reckoning each bushel p^{r} hour = to one horse and each horse = to 33000^{lbs} 1 foo^{t} high p^{r} minute. . . ."

We now turn from the "Blotting and Calculation" book record to other references which seem to indicate that the unit evolved as the result of experiment. In the *Edinburgh Review*[4] for January 1809 occurs a review of the second edition of Gregory's *Mechanics* published in 1807. Exception is taken to the following statement found in Gregory's treatise:

"What is called the horses power, is of so fluctuating and indefinite a nature, that it is perfectly ridiculous to assume it as a common measure by which the force of steam engines and other machines should be appreciated."

The reviewer takes the part of Boulton and Watt and goes on to say that the unit no doubt in itself is not very exact and subject to some variation, but that it is quite an understandable unit from the standpoint of the public. Then he says specifically:

"Boulton and Watt, however, have not left the matter in a state that can be accounted incorrect in any case, but have given to it all the accuracy that can be required, when, from the result of experiments made with the strong horses employed by the brewers in London, they have assumed, as the standard of a horse's power, a force able to raise 33,000 lib. one foot in a minute; and this no doubt, was meant to include an allowance of power sufficiently ample to cover the usual variations of the strengths of horses, and of other circumstances that may affect the accuracy of the result."

In this statement occurs, without much doubt, the first printed definition of the horsepower unit.

In 1814, five years after the appearance of the article in the *Edinburgh Review*, Watt,[5] then in his 78th year, wrote the following account of the origin of the unit:

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[4] *The Edinburgh Review* **13**, 323 (Jan., 1809).

[5] John Robison, *Steam and Steam Engines* (1818), Vol. II, p. 145.

"When Boulton and Watt set about the introduction of the rotative steam engines, to give motion to mill-work, they felt the necessity of adopting some mode of describing the power, which should be easily understood by the persons who were likely to use them. Horses being the power then generally employed to move the machinery in the great breweries and distilleries of the metropolis, where these engines came first into demand, the power of a mill-horse was considered by them to afford an obvious and concise standard of comparison, and one sufficiently definite for the purpose in view.

"A horse going at the rate of 2 ½ miles an hour raises a weight of 150 lbs. by a rope passing over a pulley, which is equal to the raising of 33,000 pounds one foot high in a minute. This was considered the horse's power; but in calculating the size of engines, it was judged advisable to make very ample allowance for the probable case of their not being kept in the best order, and therefore the load was only assumed at about 7 lbs. on the square inch of the piston, although the engines work well to 10 lbs. on the inch, exclusive of their own friction."

Thus we are apparently faced with opposing views regarding the actual origin of the horsepower unit. Are we to believe, on the one hand, the reference in the *Edinburgh Review*, and Watt's own account written in his old age that the unit evolved as the result of experiments, or are we to accept the record as it appears in the "Blotting and Calculation" book? In the absence of a definite record of experiments it seems natural to accept the latter view.

I wish particularly to acknowledge the assistance given me by Mr. H. C. Cashmore, City Librarian, Birmingham Public Library, Birmingham, England, in placing at my disposal certain rare books, and especially material of the Boulton and Watt collection residing there in the Reference Library.

Two Experiments on the Saturation Value of the Ion Current Through a Gas. An Interpretation

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THERE are three fundamental principles I believe we, as teachers of physics, should constantly bear in mind and steadfastly strive to put into practice. They are of especial importance in the teaching of modern physics.

1. A teacher should see to it that he gives his students *at least one thrill every lecture.*
2. A student learns more through performing an experiment (as the determination of e/m for cathode rays) than by reading about it in books.
3. Such an experiment should be so designed as to produce the expected result to a reasonable degree of accuracy without too great an expenditure of time, and *in addition* should reveal to the student information of value that is *totally* unexpected by him. This last I call the *surprise.*

Student experiments in connection with a course on modern physics have now, I am glad to say, become general practice; but the value of the results obtained may be largely increased by giving to them such an interpretation or extension as to bring in the element of surprise. The experiments described are familiar ones in any course on modern physics. In discussing them I shall try to illustrate the principles here enunciated.

I. *To plot the ion current through air at atmospheric pressure as a function of plate potential.* The apparatus consists of two vertical parallel brass plates, 10×10 cm and 8–12 cm apart. The collector plate is connected to an electrometer, and the other plate to a battery of potential variable up to 150 volts. X-rays pass through a lead slit and ionize a layer of air between the plates. When the electrometer deflection D in a chosen time t is plotted against increasing values of the plate potential V, the result is the familiar "saturation" curve. It reaches a maximum, under the conditions described, at about 100 volts. Since the ion current i is proportional to D, this curve shows how i varies with V. If the sensitivity s and capacitance C of the electrometer and its connections are measured, the current i is $(CD)/(300st)$ e.s.u. Let us assume representative values for these quantities as follows: $s=10$ scale div./volt; $C=100$ e.s.u.; $t=5$ sec.; $D=60$ scale div. Then $i=100\times60/300\times10\times5=0.4$ e.s.u.

Here is where the experiment usually ends. The curve for i *vs.* V is plotted and the saturation current $i_{\text{max.}}$ calculated. Values of i less than $i_{\text{max.}}$ can be accounted for by recombination of ions in transit. Everything turns out satisfactorily and quite as expected.

But now suppose we ask what fraction of air molecules per unit volume are ionized initially and directly by the x-rays. To the student this sounds interesting but appears impossible, at least without complicated apparatus and plenty of time. However, only one additional item of information needs to be supplied to him, and that comes from a study of the photographs of ion tracks in a Wilson cloud chamber. The computation follows.

Assume that the ions are all singly charged. Then, since $\epsilon = 4.77\times10^{-10}$ e.s.u./ion, we have for the total number of ions collected per second,

$$N=\frac{0.4\ \text{e.s.u./sec.}}{4.77\times10^{-10}\ \text{e.s.u./ion}}=8.4\times10^{8}\ \text{ion/sec.}$$

If the average width of the x-ray beam between the plates is 2.0 cm, the volume v of air exposed to the rays obviously is 200 cm³. Hence the number of ions collected (=number produced) per cubic centimeter is

$$n=\frac{8.4\times10^{8}\ \text{ion/sec.}}{200\ \text{cm}^3}=4.2\times10^{6}\ \text{ion/sec.}\cdot\text{cm}^3.$$

This seems large until we compare it with the number of molecules in a cubic centimeter which are capable of being ionized. This familiar number is 2.69×10^{19} mol/cm³. Hence the fraction of molecules present that are ionized every second is

$$F=\frac{4.2\times10^{6}\ \text{ion/sec.}\cdot\text{cm}^3}{2.69\times10^{19}\ \text{mol/cm}^3}=\frac{1.6\times10^{-13}\ \text{ion}}{\text{sec.}\cdot\text{mol}},$$

an astonishingly small number, and the first *surprise*. But are all these ions produced *directly* by the action of the x-rays, or are some of them secondary in origin, the result of impacts between directly liberated electrons and gas molecules? Those who have studied the ion tracks due to x-rays passed through a Wilson cloud chamber tell us that 200–300 ions are produced by each initially liberated electron in air at atmospheric pressure. Hence, if it be assumed that the average number of ions produced by each initial electron is 250, we have for the fraction of molecules directly ionized by x-rays,

$$f=\frac{1.6\times10^{-13}\ \text{ion/sec.}\cdot\text{mol}}{250\ \text{ion/electron}}=\frac{6\times10^{-16}\ \text{electron}}{\text{sec.}\cdot\text{mol}}.$$

Because this number is so exceedingly small it suggests that the x-rays used are very weak. This is true; the current through the x-ray tube is found to be about 1 m.a. What if very intense x-rays were used? A properly constructed tube can carry as much as 1 amp., though we might not want to run the tube under such conditions for as long as 5 sec. Nevertheless, if it be assumed that the x-ray output is proportional to the tube current, it might be possible thus to increase the intensity of the x-rays by a factor of 10^3. If the voltage on the tube is reasonably constant, this means a thousand-fold increase in ions produced. Hence the possible fraction of molecules present that can be directly ionized every second by x-rays is

$$p.f.=6\times10^{-16}\times10^{3}=6\times10^{-13}\ \text{electron/sec.}\cdot\text{mol}$$
$$\leqq10^{-12}\ \text{molecules ionized per second for each molecule present.}$$

Only one molecule out of every million million is ionized even by very powerful x-rays. But if x-rays are very short electromagnetic waves, as we have already learned, their expanding wave front must pass over *each* molecule; hence we should expect either an enormous effect or none at all. How then can we interpret the observed result?

Of several hypotheses suggested to account for the smallness of the effect observed the only one surviving the test of further experiment is that the structure of the x-rays is not what we have so far supposed. This is the second surprise. Instead of an expanding wave the rays consist of quanta, each traveling along a single line. The lines diverge from the x-ray target. A molecule can be ionized only when it lies on such a line; that is, when it happens to be hit by a quantum. Our results show that the fraction of molecules

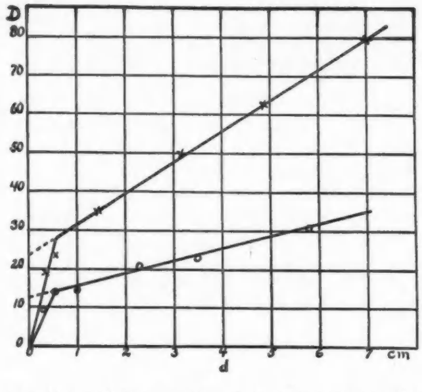

FIG. 1. Plots of D *vs.* d. For plate distances less than 0.5 cm the ions are due chiefly to corpuscular rays. If their maximum number is s and the number of ions produced in 1 cm of air path is p, then for $d>0.5$ cm the ion current is $(s+px)\epsilon$.

so hit is very small. They have led us to the quantum theory of radiation, one of the most remarkable theories in physics.

II. *To show how the saturation current between parallel plates varies with their distance apart.* The same apparatus is employed as before, except that the plate kept at potential V is replaced by a metal gauze fixed in a horizontal plane just above the lead slit, and the collector plate is mounted horizontally on an adjustable stand so that the distance d between gauze and plate may be varied from 0.20 to 8.0 cm. The potential V should be made several hundred volts so as to insure saturation at the larger plate distances. X-rays are allowed to pass through the slit and the gauze to the collector plate, and the electrometer deflection D is measured for a chosen time and for values of d from 1.0 to 8.0 cm. We find that the farther the collector plate is from the gauze the larger is D. From the point of view of Ohm's law as applied to the motion of ions through an *electrolyte* this appears to be all wrong; but since the x-rays have a chance to produce more ions as d increases, the result is to be expected after all. A plot of D *vs.* d shows a straight line (Fig. 1). But something is wrong: D should be zero when d is zero; the straight line should go through the origin. Yet if we produce our line backwards from $d=1.0$ cm to 0, it does *not* pass through the origin. Surprise number one.

Let us see how D really changes for values of d *less* than 1.0 cm—say 0.6 and 0.3 cm. We find a sharp break in the curve between 0.6 and 0.5 cm, and the new slope is such that the plot passes through the origin, as it should. Evidently we are dealing here with two ion currents instead of one, and they obey different laws. One current increases steadily with plate distance, while the other current increases rapidly up to a plate distance of 0.5 cm and then remains constant.

Now x-rays extract electrons from the molecules of a gas through which they pass; hence from this cause D is proportional to d, as was anticipated. But also, x-rays extract electrons (corpuscular rays) from *solids* upon which they impinge, in particular from both gauze and plate in this experiment; and the maximum range of such electrons is only about 0.5 cm in air at atmospheric pressure. Two surprises in one. Hence the contribution to D made by ions produced by the corpuscular rays is constant when d exceeds 0.5 cm.

It is a simple matter to calculate from the magnitude of the ion current when d is 0.5 cm how many metal atoms have been ionized, and to compare this with the number of such atoms that would be exposed to a *wave* of x-rays to a depth in the metal of, say, 10 atoms. As in the first experiment, this fraction is excessively small, which leads us to similar conclusions with regard to the quantum nature of x-rays.

Concerning the Program for the Atlantic City Meeting

APART of the program at the annual meeting at Atlantic City will be devoted as usual to contributed papers. Members who wish to submit papers should send the titles as soon as possible to the Secretary, Professor Wm. S. Webb, Department of Physics, University of Kentucky, Lexington, Ky. An abstract, prepared in a form suitable for publication [See, for example, Am. Phys. Teacher **4**, 49 (1936)] must be in the hands of the Secretary by November 15.

The Use of a Current Balance

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An effective way for the student to learn the meaning of a physical quantity is to perform the experiments in which he determines the magnitude of that quantity in terms of the other quantities involved in its definition. For example, in the calibration of a voltmeter, he can determine the magnitude of the potential difference between two terminals of a wire immersed in water, by measuring the heat liberated and the charge passed, and dividing the one by the other. Thus the concept of the volt as a joule of energy made available with each coulomb of charge is built directly from experiment.

A simple form of balance, using the attraction and repulsion of currents in straight parallel wires, affords a convenient and concise method of making absolute determinations of current, and has several advantages over the magnetometer-tangent galvanometer method. It requires less time for manipulation and is more accurate. Also the concept of current as charge flowing along a wire is not complicated by experiments with pieces of iron.

In dealing with the interaction of two currents i' and i, one of course must make sure that the amperian currents in the air or neighboring bodies are negligible. There is no need to complicate matters for the student by introducing the permeability of free space μ_0 into the equations. The descriptive word, permeability, connotes a modification by the medium of the force transmitted from i' to i. We know that even magnetized iron does not increase the force of one current on another, but merely provides other currents, amperian currents, which also act. The concept is thus left simpler if we emphasize the force of one current on the other and omit all implication that free space can modify this force, for the introduction of μ_0 in the inverse square law adds an element of vagueness, which is not desirable in elementary teaching. The omission of μ_0, if the expression for magnetic force is complete without it—and the success of three-dimensional systems of units in the hands of the many physicists who use them attests this completeness—, permits a logical step-by-step development, with permeability introduced later where it has definite physical meaning. Furthermore the magnitude of only one quantity may be determined by a single equation. If μ_0 is introduced its value must be chosen arbitrarily. Whenever used in absolute electromagnetic or practical units, μ_0 is set equal to unity or equal to a power of ten (occasionally including 4π also). Thus μ_0 is *not measured;* and whether or not μ_0 is included in the equations, the student determines his current by observations of numbers of grams, centimeters and seconds only.

To illustrate how the concept of current may be kept simple by introducing as few new physical quantities as possible, and yet be in agreement with the various modes of measurement, we may write the general equation for the total electric and magnetic force on an electron as

$$f = aq\int dq'/r^2 + bqv \sin\alpha \oint dq'v' \sin\theta'/r^2, \quad (1)$$

since $qv = il$. Simple dimensional reasoning gives at once, $b = a/c^2$, where c is a speed. The value of c is found by measurement of electric and magnetic forces to equal the speed of light. In practical cgs units,[1] $b = 1/100$; therefore $a = c^2/100$ and Eq. (1) becomes

$$f = q\int c^2 dq'/100\, r^2 + (il \sin\alpha/10)\oint i'dl' \sin\theta'/10r^2. \quad (2)$$

The first integrand is the electric field strength or potential gradient E with dq' including polarization charges. When further divided by 10^7, E is expressed in volts per centimeter. The second integrand is the magnetic field strength or flux density B, in gauss, with i' including amperian currents (B reducing to H in vacuum), and α is the angle between i and B. The last term of Eq. (2) may be regarded as the definition of current in practical units for if l and l' be connected in series, i equals i', and all the other symbols represent mechanical quantities which may be measured directly. The dimensions of i^2 (those of force since the dimensions of l, l' and r cancel) and hence the dimensions of i, $M^{1/2}L^{1/2}T^{-1}$, represent the measurements made with the current balance by which the magnitude of i is determined.[2] They may also be considered, by those who so desire, as representing the partial concept of current corresponding to this definition of i as the quantity which (besides its other properties) exerts a magnetic force on a like current.

[1] In MKS units, $b = 1/10^7$ and $a = c^2/10^7$, with f in vis, and l and r in meters.

[2] One may readily eliminate the fractional exponents by expressing grams in coul^2/cm rather than coulombs in g$^{1/2}$cm$^{1/2}$, and using coul, cm, sec. in electrical equations rather than cm, g, sec.

When the magnitude of charge is defined by another of its properties, that of electrostatic attraction as in the Gaussian system of units, $a=1$, $b=1/c^2$, and the new set of dimensions for i may be taken to represent the partial concept of current as the rate of flow of that quantity (charge) which exerts electrostatic force on a like quantity.

The introduction of c, as is preferred by Page and Adams,[3] is specific. It eliminates the difficulty of the dual meaning of the dielectric constant ϵ and the permeability μ pointed out by Webster[4] and by Birge.[5] Then Webster's Eq. (7′) becomes $D=E+4\pi c^2 P$ emu or $D=E+4\pi c^2 P/10^9$ volts/cm. Is it not easier for the student to define D as κE in each of the three-dimensional systems of units used and then remember that in emu $E=c^2Q'/\kappa r^2$ and $D=c^2Q'/r^2$ for a point charge Q', than it is to make D and E of the same dimensions in one of these systems of units and of differing dimensions in another? Then, not only are dielectric constant and specific inductive capacity synonymous (and dimensionless) as Page and Adams prefer, but also the dielectric constant is the ratio of D to E as Birge prefers, both in agreement with usage. However, unless or until a majority of physics teachers are willing to use a three-dimensional rather than a four-dimensional system of units, we must recognize the importance of unscrambling the dielectric constant and the permeability after the manner of Webster[4] and of Abraham-Becker.[6]

The Current Balance

Fig. 1 shows a current balance, for the construction of which thanks are due Mr. Karl Schneider, technician. This balance has the advantages of simplicity and ease of calculation of current.[7] It is obvious that it may be used for absolute calibration[8] of ammeters whatever system of units one may prefer. Continuing our description in the three-dimensional practical cgs system, we see that the last term of Eq. (2) gives for the magnetic field at a distance r from the long central horizontal wire carrying a current of i' amperes, $H=2i'/10r$, and for the force on current i in l cm of the horizontal sections of the loop suspended from the beam balance,

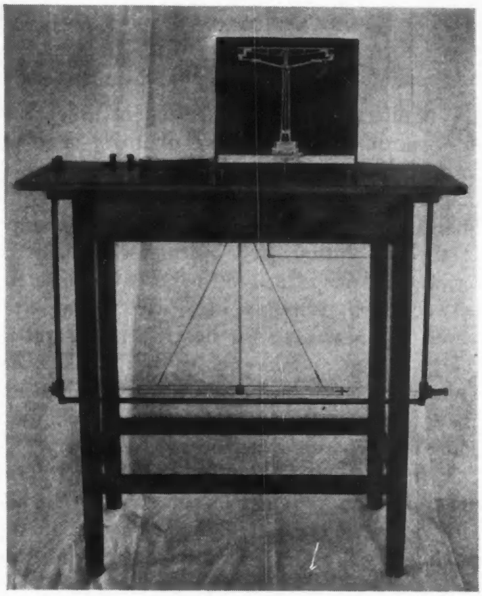


Fig. 1. Photograph of current balance.

$$f=Hil/10=2ii'l/100r \text{ dynes,} \qquad (3)$$

from which we find

$$ii'=(50rf/l)^{\frac{1}{2}}. \qquad (4)$$

Thus the square of a current or the product of two currents is measured in dynes and centimeters, a procedure which tells the student plainly that this important property of currents, the magnetic force, is used to define the ampere. The long straight wire AB (Fig. 2) is connected in series with the suspended loop of wire $LMGHJK$, which hangs from one arm of the beam balance by the rod R and the insulator S. The weight of mass m_0 placed on the pan balances the weight of the loop when no current is flowing. Wires CD, EF, NO and PQ are flexible No. 21 30-strand

[3] Am. Phys. Teacher **3**, 55 (1935).
[4] Am. Phys. Teacher **2**, 149 (1934).
[5] Am. Phys. Teacher **2**, 43 (1934).
[6] *Classical Electricity and Magnetism* (1932), p. 153.
[7] Measurement of current by this balance corresponds rather closely to a definition of the ampere suggested by Mr. Sears at the September, 1935 meeting of the Consultative Committee on Electricity and reported by Professor Kennelly (Elec. Eng. p. 11, Dec. 1935). Many other convenient forms of current balance, including that by Ainslee, R. S. I. **4**, 546 (1933), have been developed which are not used for absolute determinations.
[8] A description of the current balance used in the standard absolute determination of the ampere may be found in Bureau of Standards J. of Research **12**, 665 (1934).

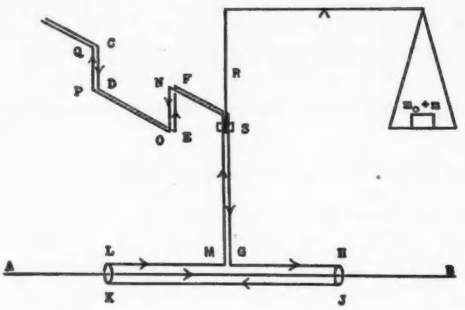


FIG. 2. Schematic diagram of current balance.

wires about 15 cm long; they allow the balance to oscillate and permit sufficient sensitivity. Wires DE and OP hang close together and the net force on them due to current in the rest of the circuit is negligible. The ends of the loop, HJ and KL, are made circular and experience no magnetic force. The length $l(=LM+GH+JK)$ is made 100 cm. The clamps supporting AB are adjustable so that AB may be centered in the vertical plane con-

TABLE I. *Students' calibration of ammeter by current balance.*

m(mg)	i observed (amp.)										i calc. (amp.)
50	5.00	5.1	5.1	5.0	5.04	4.95	5.05	4.91	4.88	4.90	4.95
100	7.00	6.8	7.05	6.80	6.95	6.98	7.03	6.81	6.92	6.80	7.00
150	8.10	8.45	8.49	8.6	8.36	8.43	8.70	8.57	8.47	8.60	8.57
200		9.66									9.90

TABLE II. *Calibration of ammeter by current balance.*

m(mg)	Ammeter reading (amp.) Direct	Reversed	Av.	i calc. (amp.)
10	2.10	2.20	2.15	2.21
20	3.08	3.20	3.14	3.13
30	3.87	3.72	3.80	3.84
50	4.97	4.92	4.94	4.95
75	6.14	6.04	6.09	6.06
100	7.04	6.94	6.99	7.00
130	8.02	7.94	7.98	7.98
160	8.93	8.92	8.92	8.84
200	9.90	9.90	9.90	9.90

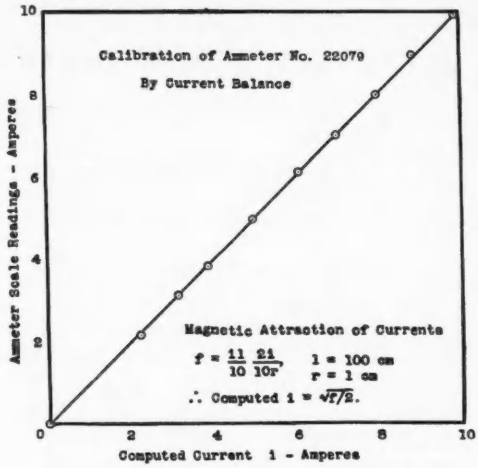


FIG. 3. Calibration of an ammeter.

taining the wires LH, JK, and half way between them. The distance between LH and JK is 2 cm so that when in adjustment r is 1 cm. In practice it is found that approximate adjustment is sufficient. In taking data, m_0 is found; then current is set up in AB as indicated by the arrow; this attracts the current in LH and repels that in JK. A mass m is added to the pan and the current is adjusted by a rheostat until a new balance is obtained. Finally the mass on the pan is reduced to m_0-m, and the current in the suspended loop is reversed and again adjusted to balance.

Table I shows data taken by the students in the sophomore course in one semester. The average deviation from the mean is 1.3 percent. Table II and Fig. 3 give the calibration of an ammeter by an instructor. With an ammeter thus calibrated for comparatively large currents, a smaller current may be determined by measuring the force of the large current i' in AB on the smaller current i produced in the suspended loop by a separate source.

Temporary Change in Address of Editorial Office

UNTIL August 1, 1937, manuscripts for publication and correspondence intended for the editorial office of this journal should be addressed to Dr. Duane Roller, Editor, Pupin Physics Laboratories, Columbia University, New York, N. Y.

APPARATUS, DEMONSTRATIONS AND LABORATORY METHODS

A Laboratory Experiment on the Analysis of Forced Vibrations

PAUL L. COPELAND, *Department of Physics, Montana State College, Bozeman, Montana*

DESCRIPTIONS of interesting experiments on forced vibrations have recently appeared. Walerstein[1] has described a simple and effective apparatus for class room demonstrations. Hull[2] has described a somewhat more elaborate apparatus for the same purpose. As a mechanical model of coupled electrical circuits Chaffee[3] has developed an ingenious apparatus capable of demonstrating numerous phenomena including the simple case of forced vibrations.

An experiment on forced vibrations is made more instructive through provision of facilities for examining the motion in detail. Theoretical analysis[4] of the problem has shown that at the part of the cycle in which the exciting force attains its maximum value F_0, the displacement D_i (in phase with the applied force) is given by

$$D_i=\frac{F_0}{m}\cdot\frac{(\omega_0^2-\omega^2)}{(\omega_0^2-\omega^2)^2+4k^2\omega^2}. \qquad (1)$$

Here m is the mass of the vibrating system, ω is 2π times the frequency of the impressed force, ω_0 is the value of ω corresponding to resonance, and k is a constant measuring the damping. (The quantity $2mk$ multiplied by the linear speed of the oscillating mass gives the damping force.) D_i when plotted as a function of ω has the form of the (anomalous) dispersion curve of optics.

The analysis has also shown that in parts of the cycle where the force falls to zero, the magnitude of the displacement D_0 (out of phase with the applied force) is given by

$$D_0=\frac{F_0}{m}\cdot\frac{2k\omega}{(\omega_0^2-\omega^2)^2+4k^2\omega^2}. \qquad (2)$$

D_0, when plotted as a function of ω, has the pronounced maximum characterizing the resonance curve.

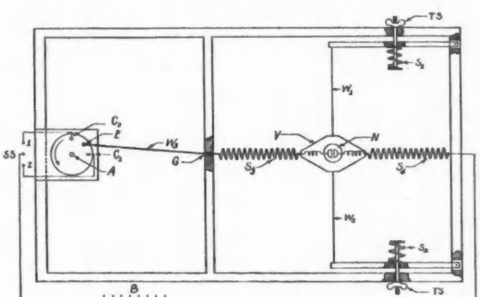


FIG. 1. Diagram of apparatus.

These ideas, given by the theory, may be shown experimentally when the vibrating system is viewed by a stroboscope of the Edgerton form,[5] the contactor of which is operated from the shaft of the eccentric supplying the exciting force. To obtain the dispersion type of curve, the contactor is operated when the applied force is a maximum. To obtain the component out of phase with the applied force, the contact is made when the force is zero.

Wherever stroboscopic illumination is available, this experiment may be performed with a minimum of effort. It is, of course, quite easy to accomplish the same result by the use of a neon lamp on the vibrating system, and in laboratories where the apparatus for showing forced vibrations has not been constructed, this is probably the best procedure even though a stroboscope is available. The apparatus designed and constructed by the writer for use in our laboratories is shown schematically in Fig. 1. The system V, a 7/8-in. board cut in the form shown and upon which a neon lamp N is fastened, vibrates horizontally in the plane of the figure. It is suspended vertically by steel wires W_1 and

[1] Walerstein, Am. Phys. Teacher **1**, 114 (1933).
[2] Hull, Am. Phys. Teacher **2**, 120 (1934).
[3] Chaffee, R. S. I. **6**, 231 (1935).
[4] See, for example, Slater and Frank, *Introduction to Theoretical Physics* (McGraw-Hill, 1931), p. 31.
[5] General Radio Catalog H, p. 2.

W_2 kept under a tension of about 10 lb. by springs S_1 and S_2. The horizontal springs S_3 and S_4 are of phosphor-bronze. A steel wire W_3, fastened to S_3 at one end, runs through the guide G and is fastened to a fiber disk by a loop around the bolt at E. A shunt motor, with a rheostat in the armature circuit to control its speed, drives the fiber disk on the shaft A which is perpendicular to the plane of the figure. As the disk rotates about its center the wire is pulled through the guide G to cause an approximately sinusoidal change of tension in the spring S_3. Springs S_3 and S_4 are always under tension, but when E has rotated to the position C_2, or to the position diametrically opposite C_2, the tension in S_4 balances that in S_3. A square of masonite, just behind the fiber disk, holds contact brushes in fixed positions at C_2 and C_1. If the selector switch SS is thrown to position *1*, the circuit through the neon lamp is completed when E makes contact at C_2; thus the lamp is flashed when the net applied force is zero. Similarly if the switch is in position *2*, the lamp is flashed when the force is a maximum. The displacement of the neon lamp from equilibrium when the lamp flashes is read on a scale.

Adjustments are provided to change several of the factors governing the motion. The mass is changed by attaching iron weights to the vibrating system V. The restoring force (and consequently ω_0 if the mass is fixed) is varied by adjusting the thumb screws TS, which change the tension in the vertical support wires. The damping, measured by k, is altered by vanes rigidly attached to V and dipping (to various controlled depths) in heavy oil contained in pans mounted on the frame of the apparatus.

Fig. 2 shows a typical set of results. Here the abscissas represent the frequency of the impressed force and the ordinates, the displacements from equilibrium. Curve 1, which has a form similar to the dispersion curve of optics, shows the displacement when the impressed force is a maximum. Curve 2 shows the displacement when the impressed force is zero. Curve 3, giving the amplitude of the forced vibrations, is computed from the ordinates of 1 and 2 by taking the square root of the sum of their squares; it has the form of the potential oscillations across a fixed condenser in the analogous electrical series resonance experiment. The amplitude of the oscillations is maximum at a frequency slightly lower than resonance.

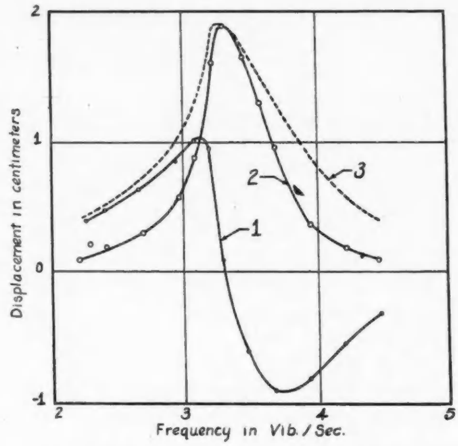


FIG. 2. A typical set of experimental results.

This experiment is in itself a study of basic principles. In addition, it is recommended by its exact and complete analogy to resonance in the series electrical circuit. Since the analogy of curve 2 to the absorption curve of optics and of curve 1 to the dispersion curve is essential, the experiment provides some basis for an understanding of these phenomena. While experience indicates that the experiment interests students who are in a position to follow the theory, its appeal is not limited to them, for the experimental problem is not difficult to understand; the approach is direct and the results obtained are definite.

The writer wishes to thank Mr. Marvin Warner, assistant in the general laboratories, for his help throughout this work.

Reprints of Survey Articles for Class Use

Reprints of Dr. L. O. Grondahl's article on "Copper-Oxide Rectifiers and Their Applications" may be obtained at cost from the Editor. The cost of 6 reprints is 40 cts. postpaid.

Young's Modulus by Vibrations

Paul F. Gaehr, *Department of Physics, Wells College, Aurora, New York*

A WEIGHT suspended from a vertical wire is capable of performing vertical vibrations, the restoring force being furnished by the elasticity of the wire. If the frequency of the vibrations can be found, then Young's modulus Y for the material in the wire can be computed easily and accurately. As was pointed out by Searle, dynamic and static methods will not give the same value of Y if there is elastic lag, the difference being smaller for smaller amplitudes. Although the dynamic measurement of Y combines the equations of elasticity with those of simple harmonic motion in an interesting and instructive manner, yet measurements of this kind appear not to be commonly described in laboratory manuals.[1] Therefore two types of dynamic measurement are described in the form used in the writer's laboratory.

Young's modulus for wires. A force stretches a wire of length L and cross-sectional area A according to the equation $F=(YA/L)x=kx$. If a mass m hangs from the wire and is set in vertical vibration, its frequency n is given by the equation $n^2=k/4\pi^2m=YA/4\pi^2mL$, whence $Y=4\pi^2n^2mL/A$.

In laying out the experiment the first step is to decide on a proper range of values for m. Since the weight of m exerts a pull, it must not exceed the value corresponding to the elastic limit for the wire; and as the oscillations produce an additional strain, it may be well to use only one-half of that value as the upper limit. One can then compute m/AY for each of the several wires under consideration by employing the approximately known value of Y. The second step is to decide on the range of frequencies that are countable with the apparatus at hand, and then to compute the appropriate range of lengths L; or else, to decide on a convenient length, and then to find for what range of frequencies provision has to be made.

If the vibrations are to be counted by eye, the frequency cannot exceed 4 vib./sec. In this case the wire must be quite long—about 25 ft. Baker[1] measures the length by swinging the wire with its weight as a simple pendulum and computing L from the observed period. As such great lengths cannot be used in the writer's laboratory, we have mounted one of only 60 cm in an apparatus like Cenco F 875, used ordinarily for measurement of stretches with a traveling microscope. Underneath the mass m, consisting of the usual laboratory iron weights, is placed an electromagnet. The coils receive an intermittent current from a Cenco spark timer, set for a convenient frequency. The value of m is adjusted for resonance, and the frequency of the impulses is measured by an impulse counter.[2]

The resonance method is more satisfactory if the current impulses are obtained from a continuously variable source, m being left constant. One can then find Y for a number of different tensions. As resonance is approached, the strength of the magnetic pull must be considerably reduced; it therefore becomes necessary to detect resonance by use of a microscope, or by projection with large magnification.

If vibrations are observed with a microscope, there should be a well illuminated fiducial mark, and this mark must remain in focus. The writer placed a small, vertical board between the wire and the mass m (Fig. 1). A hole is cut in the board. Across the back of the hole is fastened a translucent substance, such as tracing paper; and across the front is stretched a very find wire FM to serve as the fiducial mark. To hold the board board steady, two very light reeds RR about 30 cm long were attached to the back; the far ends of the reeds are inserted in a rod S which is held in a support stand. If necessary, an electric lamp may be placed behind the board. If the microscope can be moved vertically with a micrometer screw, the set-up obviously is adapted for either the static or dynamic method.

If the apparatus is placed on a table which is not too rigid, together with a motor whose arma-

[1] Professor Will C. Baker has used the method for wires at Queen's University for some years and has suggested it to me. Professor V. E. Eaton describes such an experiment in *A Laboratory Course in College Physics* (Edwards Bros., 1935), p. 20. Other methods may be found in Searle's *Experimental Electricity* and *Experimental Physics*.

[2] In a certain trial on a brass wire of length 60 cm, diameter, 0.27 mm, the frequency was 13 vib./sec., and the mass, adjusted for resonance, was found to be 1350±2.5 g.

ture is slightly out of balance, the vibrations of the motor will be transmitted to the wire. This obviates the need of the electromagnetic device and has the advantage that the frequency is continuously variable.

Longitudinal vibrations of rods. Rods whose length may be altered by magnetostriction can be given pronounced vibration if the magnetizing coils are suppplied with alternating current whose frequency equals that of the free vibration of the rod. J. M. Ide[3] has recently shown that this method of finding the natural frequency, and hence Young's modulus, gives excellent results. For rods not showing magnetostriction, other methods are available, probably familiar to most readers.

A variation in the simple experiment, involving a change of the natural frequency by the addition to the rod of equal end-weights, may be of interest to students. If several trials are made, it will be found that the square of the frequency varies linearly with the mass of the attached weights. Each end behaves like the spiral spring of time-honored memory.

Transverse vibrations of rods. Rods may be laid on sharp wedges, placed at a pair of nodal points. If the rod is of a magnetic material, one can place under any free portion a telephone receiver with diaphragm removed, the receiver being connected to any calibrated generator of alternating current; for example, a General Radio audio-oscillator. The oscillator frequency is adjusted to resonance. If the material is not magnetic, then the oscillator is connected to a suitable telephone or loud speaker, and is tuned to the rod by ear. The rod is struck with a soft hammer. The connection to the telephone is preferably made through a key, so that the sound from the oscillator may be stopped. For transverse vibrations, Lord Rayleigh[4] gives the formula $n=kbm/2L^2$, in which k is the radius of gyration of the cross-section, b is the speed of sound in the material, L is the length of the rod and m is a number arising from the theory. For the lowest note, $m^2=22.47$ and the nodes are $0.223L$ from each end. It is possible, therefore, to find b, the speed of sound; and then one may compute Young's modulus. The writer found Y for some nickel tubing by both modes of vibration and the two results agreed within 2 percent. The value of k involves measurements of the internal and external diameters of the tubing; if the wall is very thin, errors in determining these diameters may easily account for the difference in the moduli as found by the two methods.

In the lecture room, the dependence of n on L^2 is easily shown. Two bars or tubes are prepared so that one is an octave higher than the other. After the class has heard the two tones and is satisfied that they are an octave apart, the shorter bar may be laid on the chalk-tray of the blackboard, its length being indicated along the bottom of the board. Then it is raised to a vertical position, so that the two positions form two sides of a right triangle. The longer rod will then complete the triangle. Evidently, then, n varies inversely as L^2.

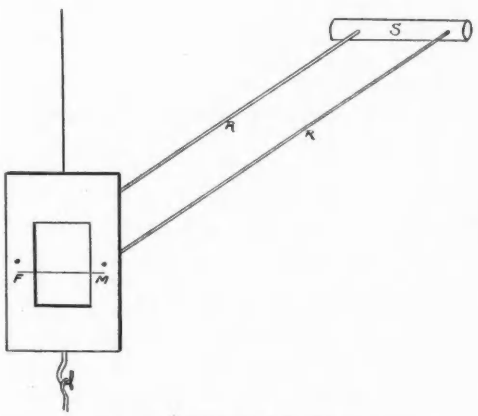


FIG. 1. Young's modulus for wires.

[3] R. S. I. **6**, 296 (1935).

[4] *Theory of Sound* (1894), Vol. I, pp. 273–278.

WHY is an object seen erect when its image on the retina is inverted? In answer to this question the equally sensible question is sometimes asked: When one hears a baby cry with two ears, why does one not take it for twins?—WM. S. FRANKLIN AND BARRY MACNUIT in "*A Calendar of Leading Experiments.*"

Electric Circuit Analysis Boards

C. R. FOUNTAIN, *Department of Physics, George Peabody College for Teachers, Nashville, Tennessee*

THE analysis board shown in Fig. 1 is one of the types of apparatus which we have developed for making laboratory experiments more practical. These boards are "fool proof" in that it is impossible to make a short circuit by any combination of switches. The main object of experiments with them is to teach the student how to trace out a circuit so that he will know how to make a current go only where he wants it. Not only will the training thus acquired be generally useful to the beginner but it makes it possible to trust him with more delicate instruments and still eliminate much of the expense and annoyance of having them burned out.

Boards with only three lamps have been in use for several years. They differ from the larger boards only in that the lamp *D* and switches 8–9 and 10–11 are omitted, the wire from 2 going directly to 7 instead of through 10. This simpler form has 14 possible combinations for the three lamps. Some students need nearly all of a double laboratory period to work out all of these combinations, make a simple diagram of the board and record the proper switches for each case.

With the larger board, using all four lamps and 11 switches, there are 45 possible combinations. If four different sizes of lamps are used, 45 different resistances are obtainable without changing any of the lamps. Some of the advantages of the larger boards are: each student may be assigned a different set of cases to solve; the brighter students or those having previous experience with radio circuits may be given more cases and more difficult ones; the chance of hitting the right combination of switches for any case by the trial and error method is extremely small.

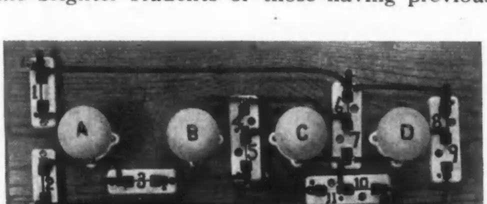


FIG. 1. Photograph of the larger analysis board.

Two experiments may be performed. The first involves only the tracing of circuits; by unscrewing a lamp the student can easily see whether it is in series or in parallel with another lamp.

Experiment 1 for 3-lamp board. Make a diagram of the board; label the lamps and switches as indicated. Connect the lamp cord to the a.c. power circuit. Record by numbers only, the fewest switches needed for each of the following cases:

Case	Lamps used	How connected	Brightness	Switches closed
1	*A*			
2	*B*			
3	*C*			
4	*A*, *B*	Series		
5	*A*, *C*	Series		
6	*B*, *C*	Series		
7	*A*, *B*	Parallel		
8	*A*, *C*	Parallel		
9	*B*, *C*	Parallel		
10	*A*, *B*, *C*	Parallel		
11	*A*, *B*, *C*,	Series		
12	*B*, *C* in series, *A* parallel			
13	*A*, *B* parallel, *C* in series			
14	*B*, *C* parallel, *A* in series			

The second experiment, which should not be given until after the first has been checked by the instructor, deals with Ohm's law for various combinations of resistances. Since the resistances of the lamps vary so much with the currents, the lamps should be replaced by plug resistors having similar resistances; these are not suitable for the first experiment, since there the student needs to see the course of the current. An ammeter and voltmeter are attached to the leads from the power circuit and the resistances of the circuit on the board for the various conditions specified are measured by the ammeter-voltmeter method. These measured values are then compared with those calculated from the known individual resistances.

IN defense of accuracy we must be zealous, as it were, even to slaying.
—P. G. TAIT.

Improvements in Two Standard Pieces of Apparatus

JOHN L. GIPPRICH AND ALFRED H. WEBER, *Department of Physics, St. Joseph's College, Philadelphia, Pennsylvania*

A FIXED pulley and a descending weight have been used to improve the operation of two pieces of apparatus used in standard experiments.[1]

Fig. 1 is a rear view of the usual dynamo analysis apparatus. The tension spring, supplied with the apparatus to produce the rotation at 10°-intervals of an armature between the poles of a set of horseshoe magnets, has been replaced by two brass pulleys *P* and *G* and a descending weight *W*. Pulley *P* is attached to the apparatus by a brass clamp the screws of which fit in between the magnets. As the weight descends on releasing the escapement, the cord unwinds from *G* which has a wide flange on which several feet of the cord may be wound. The apparatus is bolted to a finished wood base which is conveniently fastened with a C-clamp to the edge of a laboratory table.

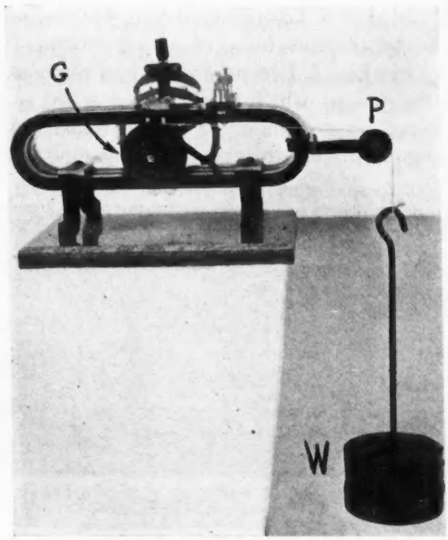


FIG. 1. Dynamo analysis apparatus.

The improvement effected is threefold: 1. The weight *W* exerts a constant torque and thus the angular speed of the armature is the same for each 10°-interval throughout a complete revolution; this is not true of the usual tension spring. 2. The angular speed can be varied merely by changing *W*. 3. Several rotations of the armature may be made without disturbing the apparatus in any way; in the original apparatus the spring had to be wound frequently.

Fig. 2 shows an apparatus for investigating the field about a bar magnet. A cylindrical magnet is enclosed in the middle third of a hollow cylindrical tube *B* which is graduated in millimeters. A search coil *C* is attached by fine, flexible leads to a galvanometer. In using the original apparatus, the search coil is flipped, by a quick thrust of the fingers, between two stops *S* which are at a fixed distance apart. This operation is repeated at successive intervals along the entire length of the magnet. In the improved form, to insure the same impulse being applied during the excursion over the whole length of the magnet, there has been added a fixed fiber pulley *P*. A brass weight *W* is attached to the search coil by means of a cord passing over the pulley. The vertical support rod and clamp are entirely of brass. The iron tripod base shown in Fig. 2 is omitted in laboratory use.

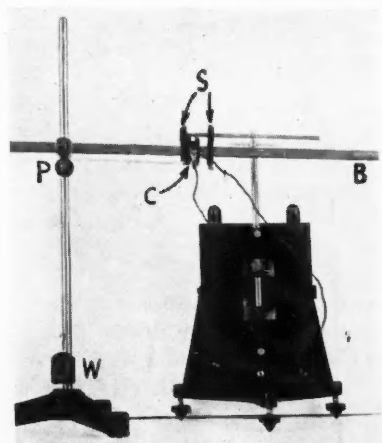


FIG. 2. Field about a bar magnet.

In operation, the search coil is held against the right-hand stop and then let go. A constant impulse is thereby applied to the coil throughout the course of the experiment.

[1] See, for example, Millikan and Mills, *Electricity, Sound and Light*, pp. 134–137.

A Laboratory Type of Traction Electromagnet

SANFORD C. GLADDEN, *Department of Physics, University of Mississippi, University, Mississippi*

A SIMPLE laboratory device for measuring the tractive force of an electromagnet is shown in Fig. 1. It consists of a half-meter stick, to one end of which is rigidly attached a soft iron rod approximately 3 in. long and 0.5 in. diameter, the end of the rod being made plane on the lathe. An electromagnet, consisting of 600 turns of B & S No. 30 cotton-covered copper wire wound on a similar rod, is supported in a system which may be adjusted so as to place the faces of the core and rod in coincidence.

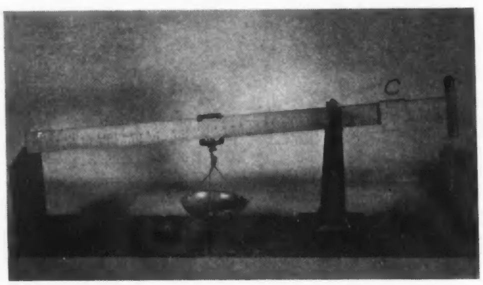


FIG. 1. Photograph of apparatus.

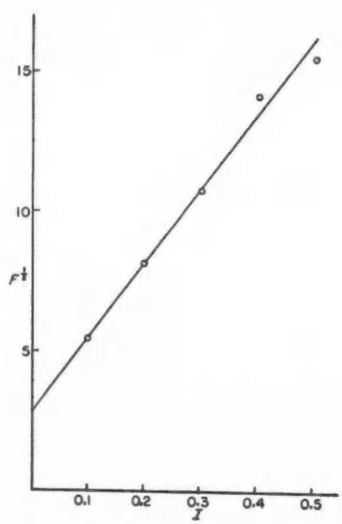


FIG. 2. Plot of $F^{\frac{1}{2}}$ *vs.* I. Note that $F \neq 0$ when $I=0$, thus indicating the presence of residual magnetism in the system.

TABLE I. *Set of student data. All forces are in grams.*

Average diameter of rod, d .... 1.260 cm.
Fulcrum position .... 37.00 cm.
Weight pan position .... 23.75 cm.
Lever arm of weights = fulcrum position − weight pan position = 13.25 cm.
Lever arm of force F = end point of stick − fulcrum position + $d/2$ = 13.63 cm.

Pan wt.	Total wt.	Wt. added	Force F	$F^{\frac{1}{2}}$	Current I, amp.
17.90	47.90	30.00	29.22	5.406	0.10
17.90	86.10	68.20	66.45	8.153	0.20
17.90	137.9	120.0	116.9	10.81	0.30
17.90	225.4	207.5	202.2	14.22	0.40
17.90	268.0	250.1	243.6	15.61	0.50

A knife-edge fulcrum is attached to the stick 15–20 cm from the end to which the rod is attached, and a weight-pan holder is supported from the stick on the far side of the fulcrum.

The following procedure is employed. The weight pan is attached to its support, and the system balanced by means of the counterpoise C until the faces of the iron rod and the core of the electromagnet barely touch. A battery is then connected to the electromagnet through a rheostat and ammeter, and the current successively changed in 0.1-amp. steps up to 0.5 amp. At each value of the current weights are added to the pan until the faces separate. The tractive force F is then equal to the weight in the pan multiplied by the ratio of the lever arms.

If the square root of the tractive force is plotted against the current, a straight line should result, providing the permeability remains constant. A set of student data is cited in Table I and plotted in Fig. 2 to show the approach to this condition.

THE percentage of freaks among people in general is very considerable, but it is especially high among teachers.—LEON TROTSKY, in "*My Life.*"

The Optimum Conditions for the Owen Bridge

HARRY E. HAMMOND, *Department of Physics, University of Missouri, Columbia, Missouri*

IN the early days of electrical measurements, it was found that the sensitivity of the Wheatstone bridge depended upon the relative values of the resistances in all six arms of the circuit. The theory of the sensitivity of this bridge was later extended to include impedance bridges that employ alternating currents.[1, 2, 3, 4] The general conclusion is that the theoretically best conditions are to have all arms of the bridge, including the source of current and the detector, of equal impedance. If this is impossible and the source and detector have different impedances, the device of greater impedance should connect the junction of the two larger arm-impedances to that of the two smaller ones. The detector should be so chosen that its impedance matches the impedance external to its terminals. The same is true of the current source. This matching may be accomplished by using suitable transformers between the bridge and source and between the bridge and detector.

In Fig. 1, let z_1 be the unknown impedance and let z_5 and z_6 be fixed in magnitude. Hague[4] states the optimum conditions for this general impedance bridge are as follows:

$$z_3=(z_5z_6)^{\frac{1}{2}}, \quad (1) \qquad z_2=(z_1z_5(z_1+z_6)/(z_1+z_5))^{\frac{1}{2}}, \quad (2)$$

$$z_4=(z_1z_6(z_1+z_5)/(z_1+z_6))^{\frac{1}{2}}. \quad (3)$$

Most of the current manuals of electrical measurements barely mention the subject of bridge sensitivity. Students therefore assume that it will be possible to balance any bridge readily, no matter what magnitudes they choose for the impedances in the ratio arms. In general this assumption is incorrect. With badly chosen values, the bridge may prove to be very insensitive or the balance may be impossible. The Anderson bridge illustrates this. Accuracy of balance often can be increased by one and sometimes by two significant figures by setting the impedances in the arms at approximately the optimum values. The computation of these values demands a knowledge of the approximate magnitude of the unknown, which usually can be obtained by inspection or by a rough test.

One very useful method for measuring an inductance in terms of known resistances and capacitances is the Owen bridge.[5] Although it is simple, easy to adjust, relatively accurate, and much used in testing laboratories, it is not mentioned in many of the manuals of electrical measurements. In Fig. 2, L and r represent the unknown inductance and its resistance; S, Q, and R are resistance boxes; C and C' are condensers with negligible resistive components. After choosing R and C, C' should be made slightly larger than C, and a balance obtained by adjusting Q and S. The optimum conditions may be computed by the use of Eqs. (1)–(3). In practice they may be approximated by a proper choice of R and C. Assume that z_5 and z_6 are equal and of fixed magnitude. Then by substituting in Eqs. (1)–(3) we obtain

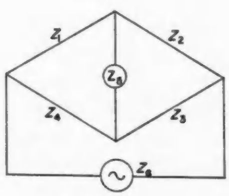
$$z_3=z_5=z_6=1/\omega C, \quad (4)$$

$$z_2=(z_1z_3)^{\frac{1}{2}}, \quad (5) \qquad z_4=(z_1z_3)^{\frac{1}{2}}. \quad (6)$$

In this bridge, $z_1=((S+r)^2+L^2\omega^2)^{\frac{1}{2}}$. Since r is usually small and S may be kept small, $(S+r)^2$ is commonly only a few percent of $L^2\omega^2$, if 1000-cycle current is used. By neglecting $(S+r)^2$, we obtain from Eq. (6)

$$R=(L/C)^{\frac{1}{2}} \quad (7)$$

as an approximation to one of the optimum conditions. Since equality of arm impedances is desirable, z_3 should be equal to z_1. Again neglecting $(S+r)$, this gives



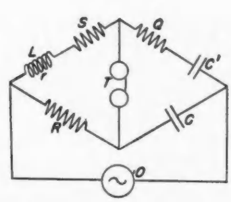


FIG. 1. Diagram of general impedance bridge.
FIG. 2. Diagram of Owen bridge circuit.

[1] L. Schwendler, Phil. Mag. (4) **31**, 364 (1866).
[2] O. Heaviside, *Electrical Papers*, Vol. I., p. 3.
[3] Rayleigh, Proc. Roy. Soc. **A49**, 203 (1891).
[4] B. Hague, *Alternating Current Bridge Methods*, ed. 2 (Pitman), p. 62.

[5] D. Owen, Proc. Phys. Soc. (London) **27**, 39 (1915).

$$C=1/L\omega^2. \quad (8)$$

A resistance Q is in series with C'; hence for equality of impedances C' should obviously be larger than C, and Q should be somewhat smaller than R.

It is not always feasible to choose the indicated values, however. The equations of balance of the bridge are

$$L=QRC, \quad (9) \qquad r=RC/C'-S \quad (10).$$

Eq. (10) shows that R must always be larger than $(S+r)$, if C' is greater than C. Two examples are shown.

For 1000-cycle current and an unknown inductance of about 100 mh, C should be about 0.3μf, R about 570 ohms. These values are neither too large nor too small and permit adjustments of Q to four significant figures. Capacitances of this size are known to four figures.

But for an inductance of about 10 mh, C should be about 3μf, and R less than 60 ohms. Smaller inductances mean larger values of C and smaller values of R. It is not feasible to use such large condensers, and the small values of R and Q would limit the adjustment to three significant figures. Hence it would be better to make R at least 100 ohms and then choose C according to Eq. (7); that is, make $C=1\mu$f. The slight loss in sensitivity will be more than compensated for by the greater accuracy of the resistances.

A Simple Laboratory Timer

HERSCHEL SMITH, *New York University, University Heights, New York City*

IN our general physics laboratories, the students perform a number of experiments that require a fairly accurate measurement of time. The stop watches which we have used, though probably satisfactory for small classes, have been very expensive for us on account of initial cost, cost of repairs, and the time lost while repairs were being made. When it became necessary to replace a number of them we decided, instead, to make timers that would have the following characteristics: low cost, reasonable accuracy, ruggedness, and simplicity so that all repairs could be made quickly and cheaply in our own shop. The timers herein described have been given a thorough trial for more than a year and have been satisfactory in all respects.

The timing system consists of a single centrally-located interrupter driven by a synchronous motor, lines to the various locations and a number of portable individually-controlled timers which can be plugged into the lines, all in parallel, as needed. The interrupter sends a pulse along the lines each tenth of a second. Each timer has an electromagnet which is energized by the tenth-second pulses. The armature of this magnet advances a ratchet wheel one notch each pulse, and this in turn operates the clock hand through a suitable train of gears.

Fig. 1 shows the interrupter. The motor turns 1800 rev./min. The ratio of the gears is 1 to 3. The shaft of the larger gear carries a cam that opens and closes a set of Ford Model A breaker points, the cam being made to keep the circuit open about half of the revolution. A $1-\mu f$ condenser is placed across the circuit breaker. The cost of the interrupter is: motor, \$17.00; materials and parts, about \$2.50; labor, about \$4.00.

The details of the timer are shown in Fig. 2 which is drawn to scale. No special reasons can be given for the various dimensions such as number of turns of wire on the magnet, number of teeth on the ratchet wheel, etc., except that the ones used were available at low cost and could be made to work. The frame is made of two $1/8\times6\times6$-in. brass plates held together by 1.5-in. brass spacers and screws. All parts are fastened to the back plate; the front plate carries only the ends of the two shafts and the face. The face was reproduced on heavy cardboard from a drawing. The "works" are held in the wooden case by two screws which pass through the bottom of the case into the bottom spacers.

The magnet *1* has about 5500 turns of No. 34 wire on a single 5/16-in. iron core. It is second hand from an old Signal Corps switchboard.

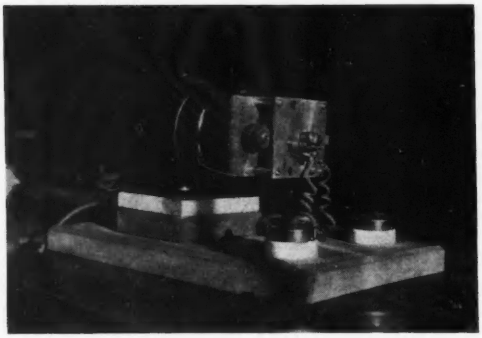


FIG. 1. Photograph of the interrupter.

The magnetic circuit is completed through the 5/16-in. iron rod *2*, and the armature *4*. The iron bracket *22* which carries the magnet is fastened to the frame by the three screws *21*, through over-size holes to allow for adjustment. It was found that about 0.1 amp. was needed to operate the timer successfully. Since the resistance of the magnet was about 300 ohms, a resistance of 850 ohms *3* was placed in series so that the system could be used directly on the 115-volt line. After the timer had been properly adjusted, the voltage of the line could be varied ± 10 volts without affecting its accuracy. The electric system was completed by a 6-ft. cord with a plug for connecting to the interrupter line, and another 6-ft. cord with a switch at its end.

The armature of the magnet *4* is $1/16 \times 3/8 \times 3$-in. iron slightly shaped to reduce weight. The spring *5* of $3/8 \times 0.015$-in. spring steel is fastened to one end of the armature and the brass block *6* with copper rivets; it provides the upward torque to the armature. The copper rivets are so placed to prevent sticking to the pole pieces. The motion of the other end of the armature is limited by the brass block *7* and the screw *8*. The steel spring *9*, $1/4 \times 0.008 \times 5/8$-in., is riveted to the end of the armature and bent so that it engages with the teeth of the ratchet wheel *10*. The spring *11*, also of $1/4 \times 0.008$-in. steel, is slightly bent on the end and serves to retard the ratchet wheel. It can be adjusted lengthwise in its brass base *12* in which it is held by the clamping screws *13*. The screw *14* adjusts the tension.

The ratchet wheel *10* is of 5/32-in. brass and has 90 teeth. It is riveted to a shoulder turned on the small pinion rod *15* which as 12 teeth. This in turn meshes with a light brass spur gear *16* of 80 teeth. The large gear with its hub turns freely on the shaft *17*, driving the shaft by friction with the spring washer and collars shown at *18*. The hand *19* can be set to any position by rotating the shaft by the knurled knob *20*. The spring *23* of $1/4 \times 0.015$-in. steel bears against the large gear and furnishes a slight friction load which prevents back-lash in the gears.

In the process of assembly, the spring *5* is given an upward bend so that when it is in position the armature bears firmly against the screw *8*. The position of the magnet is adjusted so that when the armature is down against its lower stop *7*, the pole pieces barely touch the copper rivets in the armature. The length and curvature of the spring *9* are adjusted so that with the armature down, the end of the spring is about horizontally opposite the axis of the ratchet

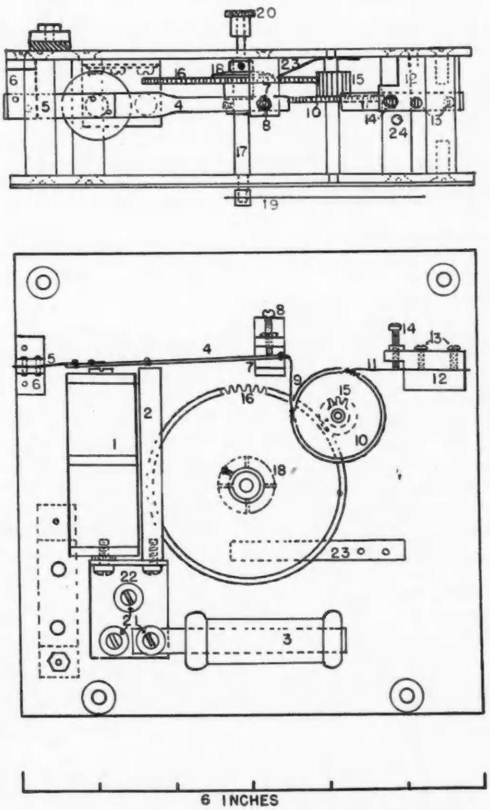


FIG. 2. Details of timer, top and front views.

FIG. 3. Photograph of the timer.

wheel and the spring presses into the notches. Next the retarding spring *11* is adjusted endwise so that with the armature down the spring just clears a notch in the ratchet wheel. The screw *8* is then adjusted so that as the armature rises from lowest to highest position the spring *9* moves up only one notch. In most cases only small adjustments of the screw *14* to alter the tension in the retarding spring will now be required to make the timer run accurately.

The ratchet wheel must be well centered to run truly about its axis; otherwise greater end-clearances are required for the springs *9* and *11* and final adjustments become extremely difficult. Too small end-clearance of either spring will cause the ratchet to stick and the timer will run too slowly or stop completely. Too great tension in the spring *11* will cause misses or a complete stop. Too great tension in the spring *9* or too sharp curvature of the end of the spring may prevent the armature from rising to the screw *8*. This usually causes a complete stop. If tension in the retarding spring is too small, or if stop screw *8* is too high, the timer will run too fast. Too great end clearance in the springs *9* or *11* will usually make the timer run fast though it sometimes allows the wheel to become locked. In general it was found that timers that ran too fast had too little tension in the retarding spring *11* or too great end-clearance in the springs *9* or *11*; and that the opposite was true for those which ran too slowly.

The cost of each completed timer (Fig. 3) was $3.35 for parts and materials and about $5 for labor. In ten weeks of continual use of our thirty-six timers, only three or four had to be removed from their cases for repairs. In each instance these consisted in slight adjustments of the screws *8* and *14*, which required only a few minutes of a mechanic's time. In former years during the same period eighteen stop watches required ten or more repairs costing from 50 cts. to $5 each, and the watches were out of use for as much as three weeks.

Teaching Aids

Motion Picture Films

Making a V-Type Engine. Silent, 16 or 35 mm, 2 reels. *U. S. Bureau of Mines,* nearest office, no charge except for transportation. This film shows the manufacture of a Ford engine from the unloading of ore boats to installation in the chassis.

Norris Dam. Silent, 16 or 35 mm, 30 min., 3 reels. *U. S. Dept. of Agriculture, Div. of Motion Pictures* (Washington), lent gratis. A TVA picture showing how the Clinch River dam was built.

Electricity on the Farm. Silent, 16 or 35 mm, 20 min. *Tennessee Valley Authority* (Washington), lent gratis. Explains many uses of electricity in rural areas.

Posters

Safety Posters. 21×28 cm. *Chicago Apparatus Co.* (1935 N. Ashland Ave., Chicago), gratis. A series of posters devoted to the crusade against automobile accidents.

Trade Periodicals

The Milvay Note Book. *Chicago Apparatus Co.* (Chicago), gratis. Apparatus and supplies; notes and brief articles.

Bausch and Lomb Magazine. *Bausch & Lomb* (Rochester), gratis. Primarily for opticians. Short biographical articles and excellent 19×21-cm reproductions of optical-history paintings in colors.

Pamphlets

Selected Papers of the Summer School for Engineering Teachers. 15×23 cm. *Lancaster Press* (Lancaster, Pa), paper cover. The following bulletins of the Society for the Promotion of Engineering Education are of particular interest to physicists: No. 2, *Historical Outline of the Electrical Units,* by A. E. Kennelly, 47 p. (1928), 20 cts.; No. 4, *Collected Papers of the Physics Session,* 70 p. (1928), 20 cts.; No. 5, *Collected Papers of the Electrical Engineering Sessions,* 131 p. (1928), 20 cts.; No. 6, *James Watt, The Industrial Revolution, and a Resume of Mechanical Engineering,* by Ira N. Hollis, Joseph W. Roe and William D. Ennis, 69 p. (1929), 30 cts.; *Four Papers on the Teaching of Mathematics,* by E. R. Hedrick, W. E. Brooke, W. J. Berry and E. V. Huntington, 70 p. (1932), 30 cts.

Every-Pupil Test in Science. Alvin W. Schindler, State University of Iowa. 8 p., 21×27 cm. Order from Prof. E. F. Linquist, Univ. of Iowa, Iowa City, Iowa, 5 cts. postpaid. A good brief discussion of the principles of test construction and of the implications of instructional objectives for achievement test construction.

DISCUSSION AND CORRESPONDENCE

Effect of an Electric Lens on Water Jets

A SUITABLE electric field can converge or diverge a beam of cathode rays just as an optical lens can converge or diverge a beam of light. Such an electric field is called an *electric lens*. This effect can be illustrated by means of water jets as follows.

A glass tube 2 cm in diameter and 30 cm long is furnished at one end with a cone-shaped nozzle which has an opening 1 mm in diameter. The glass tube is held vertically with its nozzle downward and is filled with tap water which is maintained at a constant level of about 20 cm. Thus a fine vertical water jet is formed.

Now a thin wire is put into the glass tube and connected to one terminal of an electrostatic machine. When the water is charged to high potential the water jet separates into several smaller jets. These jets do not drop vertically but diverge. When a circular ring or disk having a circular hole of several centimeters diameter is placed about 6 cm below the nozzle and is connected to the other terminal of the electrostatic machine the jets are more wide-spread Such a spreading may be interpreted as being due to an electric lens formed by the field near the nozzle. Fig. 1 shows the spreading of the jets when a ring electrode of 4 cm diameter is used. This photograph was taken under an illuminating light forming an angle of about 160° with the direction of view, for at such a direction the reflection at the inner surface of the droplets is relatively more intense, and the droplets are clearest.

When the ring is replaced by a sphere of 2.5 cm diameter the field in its neighborhood has the effect of a converging lens. The droplets passing by the sphere converge and intersect at a place below it.

FIG. 1. Diverging electric lens.

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The Electric Bell Paradox

THE bright beginner who attempts to apply the conservation principle to the electric bell, or any other device employing a make-and-break contact, may readily reach the paradox that sustained vibration must fail from lack of a source of energy. Further, the chances are against his finding help from his elementary text to set him aright.

Taking the system under consideration to include both the soft iron armature and its retaining spring, his hypothetical argument might proceed as follows. When the circuit is closed at the push-button, magnetic forces start to act. Work is done on the system until the break, when these magnetic forces cease. On the return stroke after the make, precisely the same magnetic forces come into play, but now, with the change in direction of the motion, the sign of the work changes. The work previously done on the system is now undone. In a complete cycle the net energy supplied is zero. The demands of sound waves and of air friction cannot be met. In short, the bell won't work!

The fallacy of this argument lies of course in neglecting the retardation of the current. The magnetic forces are not in step with the motion of the armature, but are greater as it moves toward the magnet. The net work done on the system, therefore, is positive and not zero. This retardation of the current may be due to any of three causes. First, on account of the lack of sharpness in the break, an arc may prolong the current beyond the point at which it starts at the make. Second, the make-and-break contact may be attached, not directly to the armature, but to a light auxiliary spring which the armature forces into vibration with a definite phase lag. Third, because of the inductance of the circuit, the current does not instantaneously rise to its full value.

Our beginner will have little better luck with his textbook of electricity than with his elementary text in finding an explicit explanation, although Pilley's *Electricity* (1933) in a footnote on p. 228 meets the issue. If, however, he turns to the discussion of electrically driven tuning forks in his books on sound, he will find all that is desired. Rayleigh, *Theory of Sound*, ed. 2, Vol. I, p. 68 and A. B. Wood, *A Textbook of Sound* (Macmillan, 1930), p. 121, are particularly complete.

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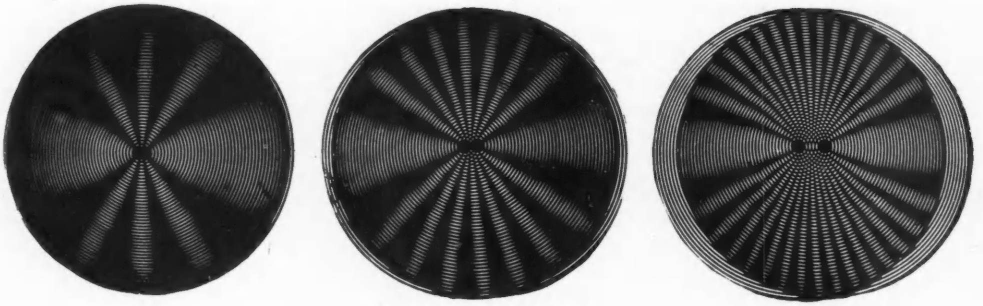

FIG. 1. Photographs of patterns.

Demonstrating the Principles of Interference

C. E. MILLER [Am. Phys. Teacher **3**, 75 (1935)] has described a device for demonstrating the principles of interference which consisted of two lantern slide plates, one a photograph of a drawing of a series of concentric, equally spaced circles, the other a negative of the first. When the two plates were placed together, a series of dark lines could be seen, the lines resembling the interference lines produced by two sets of waves of equal period and wave-length, but 180° out of phase. A pattern corresponding to two sets of waves not out of phase evidently would be produced by two plates of the same kind and, as Miller remarks, this would be the preferable way, but he regards the realization of it difficult in practice.

Since the spring of 1931 I have used a device much like that described by Miller but consisting of two plates of the same kind, and that without undue difficulty. Photographs of patterns obtained with this device appear in Fig. 1 and are comparable to those in Fig. 1 of the paper by Miller. To obtain the plates a drawing was made of the pattern in Fig. 2. The completed drawing which was made on stiff cardboard, was cut down to a disk of 70 cm diameter and this disk was fixed to the axis of an electric motor. The rotating disk was photographed directly on a lantern slide plate, on which a series of concentric, alternate black and white circles was obtained. From this lantern slide a first contact print was made, from the first contact print a second, and this second one was used as second plate of the device.

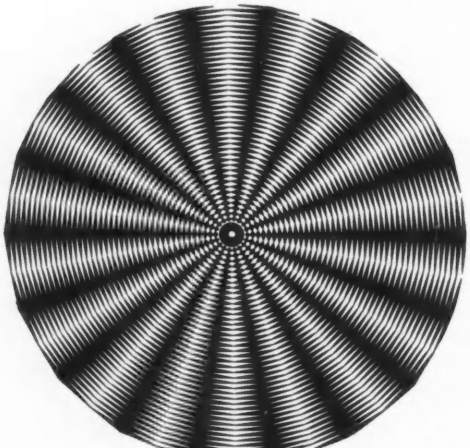

FIG. 2. Patterns for drawing.

Nevertheless, at this stage the interference pattern still retained a dissymmetry of the same kind as shown in Miller's patterns, in which the shadings of the right-hand side differ from those on the left-hand side, this being due to distortions of the nominal circles into some kind of ovals. But this difference in shadings could be easily annihilated by rotating one of the plates in its own plane. Accordingly the slide holder was constructed so that one of the plates was held in a fixed position whilst the other could be moved by means of two micrometer screws and a handle. The screws effected sliding motions up and down, and from right to left, respectively, the handle a rotating motion about the optical axis of the projection lantern.

The described plates produce interference patterns due to two point-like sources of light. Attempts were made to prepare plates for producing patterns due to three and four collinear point-like sources, plates that might be used to display the general alterations of interference patterns which accompany the transition from two sources to three and four and the originating of secondary maximas. But the results were unsatisfactory and these attempts were not pursued farther.

Mrs. A. Sprantzmann collaborated in developing this method.

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. . . BEHIND all your practical applications, there is a region of intellectual action to which practical men have rarely contributed, but from which they draw all their supplies. Cut them off from this region, and they become eventually helpless.—JOHN TYNDALL in "*Lectures on Light.*"

Laboratory Exercises on Examining Colors

IN a recent issue of the Polish journal *Fizyka i Chemja w Szkole* we have printed a translation of Mr. Heilemann's interesting article on a lantern slide color mixer [Am. Phys. Teacher **3**, 184 (1935)]. We have taught color vision for many years on somewhat similar lines in our laboratories for elementary schools and for junior classes of secondary schools and in this note are describing the teaching method and the simple apparatus used in the hope that they will be of some interest to American readers.

Subjective Synthesis of Colored Rays

On a wooden base (Fig. 1) are fixed 2 wooden pillars A 11 cm high, and 1 pillar B 13 cm high. They can revolve around their vertical axes. The upper part (5 cm from top) of the pillar B can also rotate somewhat around a horizontal axis. At the top of each pillar a small electric lamp is fixed (Fig. 2), each lamp being surrounded by a metal tube 16 mm in diameter and 4 cm long, connected with a square frame CC (Fig. 1) into which colored glass plates may be slipped. On the front side the frame is connected with a wider tube, 24 mm in diameter and 6.5 cm long (Fig. 2).

A screen, 20×20 cm in size, made of thin wood and painted white, also is needed.

For each apparatus five 4.5×3-cm colored glass plates are needed, *viz.*, red, orange, green, blue and dark blue. If no suitable filters are available they can be made easily by dissolving in water the colors used for dyeing cotton, adding some gelatine and covering an ordinary glass plate with a very thin layer of this solution. A piece of cardboard, 4.5×3.5 cm, is placed in the slide-frame to shade one of the lamps when only two colors are to be mixed.

Mixing of colored rays. Each group of 3–4 students receives a set of instruments. The room ought to be darkened. In the central tube is placed a blue filter and in the lateral tubes a green and a red one. The screen is placed at a distance of 25–30 cm from the lamps and the tubes are directed toward it. When the lateral tubes are placed parallel to each other and the central one is directed somewhat upwards, three colored spots will be observed on the screen (Fig. 3*a*).

When the lateral lamp-stands are rotated about their vertical axes so as to cause the red and green spots to overlap (Fig. 3*b*), the common part appears yellow. The red and blue spots when overlapped produce a sensation of amaranth; the green and blue, a sensation of faint blue. When the red, green and blue spots overlap the effect produced by the mixed colors is exactly that of white light (Fig. 3*c*).

Complementary colors. A piece of cardboard is placed in the central tube, and blue and orange filters in the lateral ones. When the colored spots are made to overlap, white results. Other complementary colors—violet and green, or amaranth and green—may also be used.

Incapacity of the eye to distinguish components of colored rays—Principle of color photography. Three specially painted screens in black frames 12×14 cm in size are placed on a blackboard and illuminated strongly from below with a shaded, 500–1000 watt lamp. When observed from a distance of 5–12 m: one frame seems to contain clean, white paper; the second, three adjacent rectangles colored red, green and light blue; the third, a solid color intermediate between pink and violet.

Closer examination shows that the screen which seemed to be white actually is covered with a large number (9 per cm) of closely drawn red, green and pale blue lines, the colors alternating. The lines are made 0.5 mm wide. The colored rays from these lines reach our eye and on mixing, produce the impression of white; our eye evidently is unable to distinguish the components of the white light. The frame with the paper on which we had noticed the colored rectangles also contains three sets of colored lines —red, green and light blue—of the same number, width and tinge as those on the first screen, only here the lines of one color are all grouped together. The difference of impression depends solely on the arrangement of the lines

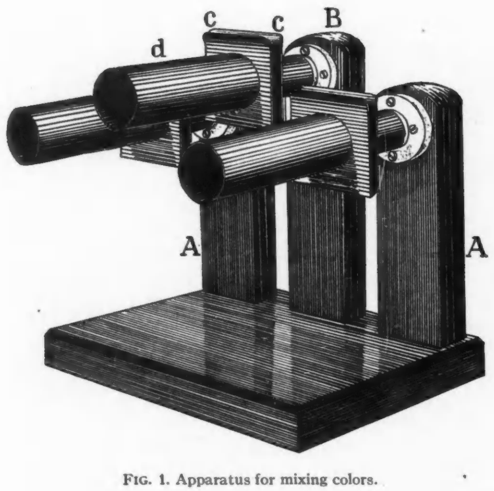

FIG. 1. Apparatus for mixing colors.

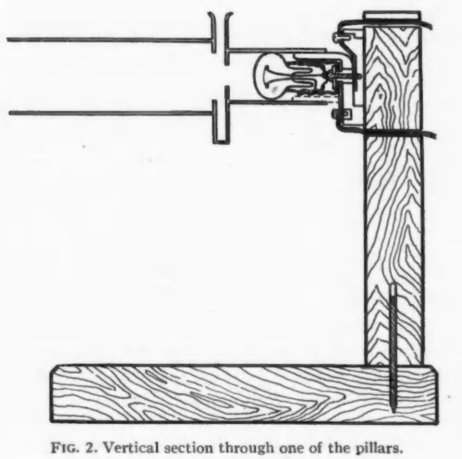

FIG. 2. Vertical section through one of the pillars.

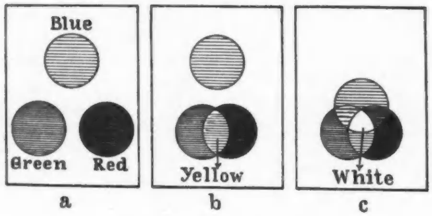

FIG. 3. Effects of mixing colors.

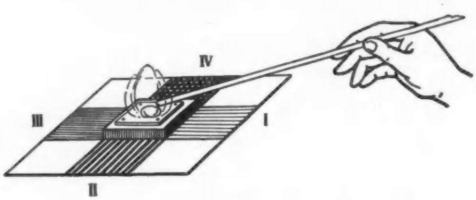

FIG. 4. Effects of quality of light on colors of objects.

on the screen. On comparing the third frame with the first, we notice a lack of green lines: on that paper only red and faint blue lines have been drawn; by acting simultaneously on the eye, they give the impression of a pinkish-violet color which the eye is unable to resolve into its components.

COLORS OF OBJECTS DEPEND ON QUALITY OF LIGHT

On a piece of drawing paper 14×14 cm in size are pasted four 5×5-cm squares of glossy colored papers: orange, green, light blue and dark red. This paper is placed on a table besides a lamp in a darkened room and in the middle of the paper is placed a small board with a tin plate containing a piece of cotton wool soaked in alcohol. The cotton wool is then lighted and touched with a chip of wood soaked in a saturated salt solution (Fig. 4). When the light is extinguished or shaded with the hand, it will be observed that the colors of all the papers have changed: the orange now appears yellowish; the pale blue becomes dark blue; the green, black; the red, dark brown. On relighting the lamp the original colors reappear. Consequently the color of a body depends both on the body itself and on the quality of the light by which it is illuminated.

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Reviving the Sonometer

EXPERIMENTS with a sonometer are often omitted in an elementary laboratory course, for the standard forms of the experiment are very dull and more elaborate forms usually demand a more detailed knowledge of musical scales than a beginner has time to master. The following variation has been used with great success for Arts and Science students, and for students who take short non-technical courses. The instructions are quoted from our laboratory manual.

The laboratory sonometer has two wires of the same material and thickness. One is stretched a little tighter than the other; . . . The note which it emits is to be used as a standard, and may be called *do*. Place the bridge under the slacker of the two wires, near the fixed end, and adjust its position until this wire is also sounding *do*. Measure and record its length. Now move the bridge until the slacker wire sounds *re*, as judged from the *do* of the standard wire. Measure and record its length. Continue thus up the major diatonic scale for two and one-half octaves or more.

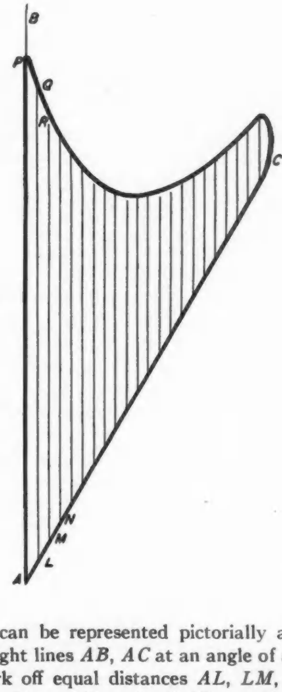

FIG. 1.

The results can be represented pictorially as follows. Draw two straight lines AB, AC at an angle of about 30°. Along AC mark off equal distances AL, LM, MN . . . each 1 cm long. Along AB mark off AP to scale such that AP represents the length of the test wire corresponding to the note *do*. A scale such that AP is actually one-fourth as long as the test wire will probably be found convenient. Now from L draw a line LQ parallel to AP, and of such a length as to represent, on the same scale, the length of the test wire corresponding to the note *re*. Then from M draw MR to represent the note *mi*, and so on throughout the range of your experiment. The clue to the completed diagram (Fig. 1) is in a symphony orchestra.

The student then goes on to compare the reciprocals of the lengths of wire corresponding to the notes of one octave of his scale with the usual series of frequency-ratios 24, 27, 30, etc.

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The Motion of a Weight with Attached Rope

THE following problem appeared in the September, 1935 issue, page 138:

> Flexible rope of mass 2 lb./ft. is coiled on the ground, with one end tied to a 20-lb. weight. The weight is thrown upward with an initial speed of 30 ft./sec. It rises and pulls after it an increasing length of rope. With what kind of motion, and how high, will it rise? Describe the motion by giving the coordinate of the weight in terms of the time.

This problem is a variation of the first one in the same letter, in which rope was pulled horizontally from a stationary coil, a complete solution of which has now appeared [R. T. Birge, Am. Phys. Teacher **4**, 43 (1936)]; the correct value of the force is given by the time rate of change of momentum. To equate the work done to the kinetic energy of the rope gives an incorrect result because any bit of the rope, as Professor Birge explains, is set in motion by an inelastic impact, and half the energy expended in so doing appears as heat. An additional interest in the second problem lies in the means of solution, as shall now appear.

Using a coordinate system with x measured upward from the ground, the initial velocity $\dot{x}_0$ is positive and the acceleration due to gravity is negative. In this particular case $m=20$ lb., $\rho=2$ lb./ft., and $\dot{x}_0=30$ ft./sec. Although it would not be possible to measure these quantities with unlimited accuracy, we shall take the integers to represent their actual values. The moving system is retarded by the weight of m and whatever rope is in the air, and, taking force equal to time rate of change of momentum, and g as $+32$, $-(m+\rho x)g=d[(m+\rho x)\dot{x}]/dt$. From this

$$(m+\rho x)\ddot{x}+\rho(\dot{x})^2=-(m+\rho x)g. \tag{1}$$

Let $m+\rho x=y$; then $\rho\dot{x}=\dot{y}$ and $\rho\ddot{x}=\ddot{y}$, so that $y\ddot{y}+(\dot{y})^2=-\rho gy$ or $d^2y^2/dt^2=-2\rho gy$, which may be checked by differentiating y^2. Then if $y^2=z$, $d^2z/dt^2=-2\rho gz^{\frac{1}{2}}$. Here $2dz/dt$ is an integrating factor; hence

$$(dz/dt)^2=-(8\rho gz^{\frac{3}{2}}/3) \tag{2}$$

$+C$. Returning to x,

$$dz/dt=2(m+\rho x)\rho\dot{x}$$

and

$$4(m+\rho x)^2\rho^2\dot{x}^2=-8\rho g(m+\rho x)^3/3+C. \tag{3}$$

Since $\dot{x}$ is 30 ft./sec. when $x=0$, $C=7{,}125{,}333$. Eq. (3) enables one to find $\dot{x}$ for any value of x, and with corresponding values of x and $\dot{x}$, Eq. (1) gives the acceleration $\ddot{x}$. Moreover, from Eq. (3), since $\dot{x}=0$ for maximum x which is h, $h=7.3456$ ft. This is the final height. The corresponding acceleration is -32 ft./sec.^{2} Also, from Eq. (1), at the start, when $x=0$ and $\dot{x}=30$, $\ddot{x}_0=-122$ ft./sec.^{2}

However, a second integration, or solution of Eq. (2), is necessary in order to express z (and x) explicitly in terms of the time t and so to satisfy the second requirement. Eq. (2) may be written

$$dz/(C-8\rho gz^{\frac{3}{2}}/3)^{\frac{1}{2}}=dt, \tag{4}$$

and $\int dz/(C-az^{\frac{3}{2}})^{\frac{1}{2}}$ is an elliptic integral, and accordingly not to be expressed in terms of ordinary functions. Moreover, it is not readily reducible to one of the standard forms. Various transformations have been carried out, but no integrable form has appeared. This impasse in the solution of so natural and simple a problem will strike the amateur mathematician as incongruous. However, since a numerical result is desired, it should be possible, all constants being given, to write the integrand as a series and integrate term by term. Accordingly let $8\rho gz^{\frac{3}{2}}/3C=u$; then Eq. (4) becomes $0.300569u^{-\frac{1}{3}}du/(1-u)^{\frac{1}{2}}=dt$, where $u^{-\frac{1}{3}}/(1-u)^{\frac{1}{2}}$ is readily expanded. But one finds, after integrating, that, in order to determine the total time of ascent, u must be 1, and the series, though by test convergent, converges so slowly that, after summing 20 terms or more, one has no idea how near he may be to the actual definite time necessary for the block to come to rest. A better expedient seems to be a numerical integration, carried out as follows. In Eq. (4), let $8\rho gz^{\frac{3}{2}}/3C=\sin^2\theta$. Then $z=\sin^{4/3}\theta/(8\rho g/3C)^{\frac{2}{3}}$ and $dz=4\sin^{\frac{1}{3}}\theta\cos\theta d\theta/3(8\rho g/3C)^{\frac{2}{3}}$; therefore

$$C^{1/6}\sin^{\frac{1}{3}}\theta d\theta/3^{\frac{1}{3}}(\rho g)^{\frac{2}{3}}=dt,$$

or

$$0.601138\sin^{\frac{1}{3}}\theta d\theta=dt. \tag{5}$$

Recalling that at $x=0$, $z=m^2=(20)^2$, and at $x=h$, $8\rho gz^{\frac{3}{2}}/3C=1$ [from Eq. (2)], Eq. (5) gives

$$0.601138\int_{\theta=25°\,57'\,35''}^{\theta=90°}\sin^{\frac{1}{3}}\theta d\theta=t.$$

Then $0.601138\times$(area from $\theta=25°\,57'\,35''$ to any value of θ, say θ_1) gives the time from the start until the weight has reached the height x_1, given by $8\rho g(m+\rho x_1)^3/3C=\sin^2\theta_1$. Taking θ in succession as 25° 57′ 35″, 25° 58′, 26°, 30° and then at 5° intervals, the corresponding values of t and x are given in Fig. 1, Curve 1, where it appears that the total time of ascent is 0.6212 sec. Equal steps in angle give points almost uniformly spaced along the time axis. Here the chord of the 5° interval was used for the arc and the value of t is too small. But trying again with 10° intervals from 30° up gave a difference in the value of t of less than 1 percent and t is perhaps 0.1 percent small. One could take 2° intervals and could, in short, get a value as close to the true time as might be required. Between 30° and 90°, $\sin^{\frac{1}{3}}\theta$ changes only from 0.8 to 1 and the line is more nearly straight than the sine curve. Curves 2 and 3, Fig. 1, give the velocity and acceleration. One might expect more difference between the times of ascent and descent. However, the area above 3 gives the corresponding change in 2, and the area beneath 2 the corresponding change in 1, leaving no outstanding incompatibility.

If some of the original energy of the weight is transformed into heat as it rises, there should be a difference between that original energy and the potential energy

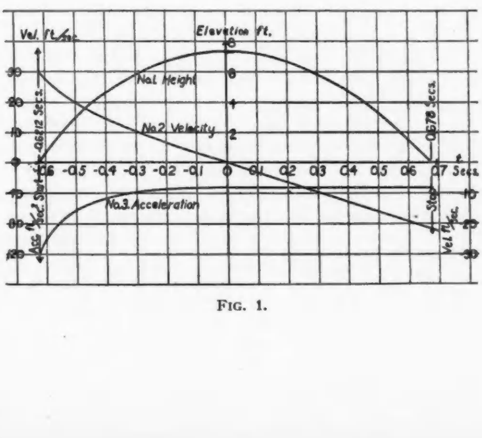

Fig. 1.

represented by the block and rope when they come to rest with the weight at its greatest elevation. For the kinetic energy at first, $mv^2/2=20\cdot 30^2/2=9000$ ft. poundals. The maximum potential energy is mgh (for the weight) $+\rho h^2 g/2$ (for the rope), so that P. E. $=6427.8$ ft. poundals. The difference is 2572.2 ft. poundals. This can be accounted for as follows.

Any element of the rope whose mass is ρdx is set in motion with velocity $\dot{x}$ and its initial kinetic energy is $mv^2/2$ or $\rho dx(\dot{x})^2/2$. According to the conditions for inelastic impact an equal amount of energy appears as heat in the rope, and therefore the total amount of heat should be given by $H=\rho/2\int_{x=0}^{x=h}(\dot{x})^2dx$. Since $(m+\rho x)=z^{\frac{1}{2}}$, we look to Eq. (2) and find by simple processes that

$$H=-\frac{g}{6\rho}\int_{z=m^2}^{z=(m+\rho h)^2}dz+\frac{C}{16\rho^2}\int_{z=m^2}^{z=(m+\rho h)^2}z^{-3/2}dz.$$

Therefore

$$H=\frac{-g}{6\rho}[(m+\rho h)^2-m^2]-\frac{C}{8\rho^2}\left[\frac{1}{m-\rho h}-\frac{1}{m}\right]$$
$$=2572.2 \text{ ft. poundals,}$$

quite as before. This amount is about 0.1 B.t.u. A student might find this simple check exhilarating.

Fig. 1 shows th e descent of the weight with constant acceleration, -32 ft./sec.^{2}, and x giving a parabola, with the required time 0.67757 sec. It is noticeable that there is no discontinuity at the vertex in any of the lines, and also none in the slope of the acceleration curve.

The problem of drawing out the rope horizontally was constructed a few years ago as an illustration of the definition of force in a situation where $F=ma$ could not readily be used. I supposed such problems had been given, though I had never seen one. In order to vary the solution I tried to use K.E. $=FS$, and I did not understand for some time why the discrepancy occurred. Finally the reference to "falling chains" in the sonnet of dedication in Crabtree's *Spinning Tops and Gyroscopic Motion* sent me to W. H. Besant's *Dynamics*, where I found the explanation. Afterward I realized that the equations for the loss of energy in impact, as given in Carhart's *Physics* (which I had taught) contained the whole idea. Problems involving a continuous change of mass have been given many times, and in his *Dynamics of a Particle* (1898), p. 80, Routh refers to several variations, some of them very complicated, including the problem of a raindrop gathering droplets in its fall. Routh proposes a problem of a weight with chain attached and gives as answer a general expression for the final height which checks the result here obtained. In no case, however, so far as I have found, is the time of ascent required or any general time relation suggested.

For the solution given here I am much indebted to the interest of Professor Dennison. One might suppose that a direct attack on a different front would give a literal solution, but such a result must mean the evaluation in elementary forms of this particular integral.

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An Experiment to Demonstrate that "Frictional" Electricity Depends on Contact Potential

THE production of a charge on a sealing-wax rod when it is rubbed with cat's fur is often explained as due to "friction," some connection between the work of overcoming friction and the work of creating the charge being indicated. In order to demonstrate the role of the contact potential set up between materials electrified by "friction," R. W. Pohl[1] describes an experiment in which a piece of paraffin is dipped into water to create a charge. Pohl gives an adequate theoretical treatment of the effect, but his description of the actual experiment does not seem so adequate. At the suggestion of Professor H. B. Lemon the writer set out to develop a demonstration experiment that would enable one to exhibit the effect with an ordinary projection electroscope. Details of the experiment as it is now being performed at the University of Chicago are presented herewith.

A fiber tube 5 in. long and 4 in. in diameter is fitted at one end with a handle of hard rubber, the handle coinciding with the long axis of the cylinder. The tube is given an internal and external coating of paraffin about 5 mm thick by dipping, in much the same way in which hand-dipped candles are made; a dozen "dips" may be required to accumulate a thick enough coating. An insulated metal container, large and deep enough to hold the paraffined tube, is filled with clean water (preferably distilled) and connected to an ordinary lecture-table electroscope. Removal of the immersed paraffined tube will leave sufficient charge on the electroscope to deflect the leaves about 45°. The sign of the charge left in the water and thus on the electroscope leaves is positive. Replacing the same tube in the water will cause the leaves to collapse. It is possible to increase the deflection beyond that for one immersion by discharging the paraffin over a bunsen flame, by means of the gas ions coming from it, and then repeating the process.

After several months a coating of conducting dirt may accumulate on the paraffin surface and the electroscope will fail to show a deflection. The effect may be completely restored by slightly melting the paraffin surface over a flame.

Stanley Anderson

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The University of Chicago,
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[1] *Physical Principles of Electricity and Magnetism* (1930), p. 61.

A Demonstration of the Pile Driver

IT is unfortunate that so few boys see a pile driver in action since it furnishes an excellent example of the obtaining of work from kinetic energy as well as of obtaining a large force by the rapid change of momentum. In keeping with our practice of providing special problems for the better students, a demonstration pile driver has been prepared which lends itself to actual measurements. Fig. 1 shows the simple apparatus designed for demon-

stration. The driver is cut from a piece of cold rolled steel of diameter 1.5 cm, length 5 cm, and mass 68 g. A piece of light twine is tied to a ring in the top. The ways are provided by a 47-cm piece of glass tubing having an inside diameter just a bit larger than the diameter of the driver. The tube provides a free fall of 39 cm. The pile is made from a piece of No. 12 drill steel, mass 39 g, and goes through a No. 4 one-hole rubber stopper. This, in turn, is put in a tapered hole in a piece of wood that is supported on a ring stand. The pile is hooked on its lower end so that weights may be applied to demonstrate the resistance. When the stopper is pushed into the wood tightly, the pile was found to support a load of more than 4 kg without slipping. Letting the driver drop on the pile, however, produced a displacement of about 4 mm, and successive blows produced a displacement that was easily seen throughout a large room.

To adapt this apparatus for quantitative experimentation, an adjustable wooden vise was substituted for the rubber stopper. The vise was securely fastened to a heavy weight (25 lb.) and supported the pile just over the edge of a table. The jaws were adjusted before each blow or each series of blows so that they permitted slow slipping of the pile with the desired load hanging from the hook; it was necessary to tap the load in order to overcome the starting friction. The load was then removed, the blow struck, and the displacement measured.

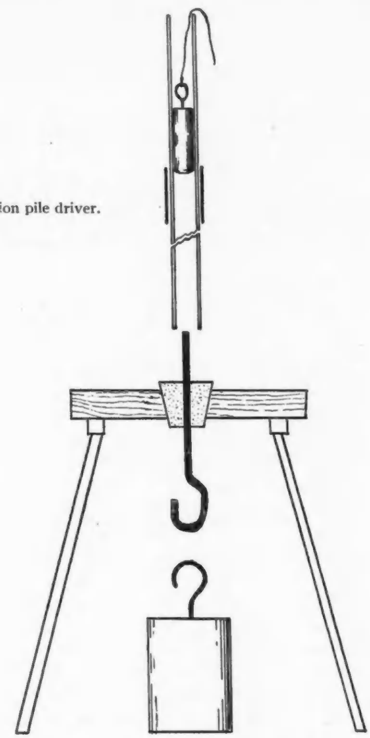

FIG. 1. Demonstration pile driver.

On the assumption of an inelastic impact, one can develop that the displacement x is related to the mass M' of the load by the equation

$$x[M'-(m+M)]=M^2h/(m+M), \qquad (1)$$

where m is the mass of the pile, M the mass of the driver, and h the fall before impact.

The sample results being reported were obtained using two different loads but no other changes, though such are obviously possible. Thus the right-hand member of Eq. (1) is a constant which for the data quoted above has a value of 1690 g·cm. For $M'=4110$ g, the average x for 5 single blows was 0.452 cm, and the left-hand side of Eq. (1) becomes 1810 g·cm; and the average x for 5 successive blows was 0.412 cm, and the left-hand side of Eq. (1) becomes 1650 g·cm. For $M'=5617$ g, the average x for 5 single blows was 0.350 cm, and the left-hand side of Eq. (1) becomes 1930 g·cm. These values are thought to check rather well considering the type and simplicity of the experiment.

I wish to express my appreciation of the assistance of Mr. Everett Smith in the construction of the apparatus.

ANDREW LONGACRE

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Award for Best Popular Science Manuscript

A CASH award of **$1000.00** is offered by The Williams & Wilkins Company, Baltimore, Md., for the best manuscript on a science subject, presented before July 1, 1937. There is no limitations on the subject-matter or manner of handling, and none on eligibility for the award. The manuscript must be in English and "of a sort calculated to appeal to the taste of the public at large." The desired length is given as 100,000 words. While any manuscript on a science subject will be considered, it is expected that the author will prove to be a man or woman engaged in a scientific pursuit who is possessed of the requisite literary skill to interpret science for that portion of the public which reads books.

To assure authenticity, the publishers have enlisted the services of some 25 "advisers," these being men of science of wide reputation and assured competence; one or more of the advisers will pass on each manuscript from the point of view of soundness and accuracy. The award will lie in the joint discretion of four judges selected with a view to their especial qualifications in choosing the sort of book that will appeal.

Recent Publications

Back to Newton. GEORGE DE BOTHEZAT. 159 p., 15×23 cm. *Stechert*, $2.50.

"'*Back to Newton*'—we sinners who have already erred too long on the slippery paths of Einstein's misleading and confusing relativity" (p. 11).

With this slogan emblazoned on his banner, George de Bothezat sets out to slay the Dragon of Relativity. But the way is tortuous, and beset by many pitfalls which must first be overcome. Armed with a metaphysical lance called "cognitive rationalism," de Bothezat first tilts at the notions of number, infinity and Non-Euclidean geometry commonly accepted by mathematicians of the present—and finds (p. 70) that on recasting them Euclid's famous parallel postulate "is but a direct consequence of the definition of infinity!" Having thus, in 77 pages, set aright the mathematicians from Gauss down, our author valiantly attacks the problem of time, motion and space-time. In order to dispose of the relativistic aura built up around these notions, de Bothezat calls (pp. 95–114) upon the aid of a Creator, who is to play the role of an Absolute—although one has here the feeling that this appeal is more a gracious concession on the part of the author than a supplication. Affirming (p. 104) the significance of "Newton's belief in the conception of absolute motion *to which we have only given a final rigorous meaning*," and again chanting his slogan, de Bothezat now sights his quarry, Relativity, and the fight is on!

But let us here mercifully draw the curtain, for a closer scrutiny shows that what de Bothezat attacks is but a caricature of Einstein's relativity. A deep-seated misunderstanding of the principle of equivalence, together with a flagrant misuse of the analogy between sound and electromagnetic waves, leads the author to most sweeping and baseless assertions concerning the untenability of Einstein's position. The dragon our modern George has slain is but of papier maché, without bones or sinew, which could only be mistaken from afar—or through distorted glasses—for the quarry which he has set out to destroy!

To return to the world of ledger sheets and book reports, it is indeed amazing that a reputable firm would risk the publishing of such a book under its own imprimatur, and yet more amazing that it would assume unto itself the sanctioning of the scientific verity of the author's claims in its widely distributed advertisements. Must it be assumed that we have before us here but another of those irresponsible attacks on this branch of mathematical physics, attacks which have become of late only too prevalent in quarters where, for political or other extra-scientific reasons, the foremost author in the field cannot be tolerated nor his views countenanced?

H. P. ROBERTSON

FIRST YEAR COLLEGE TEXTBOOKS

A Survey of Physics for College Students. FREDERICK A. SAUNDERS, Professor of Physics, Harvard University. Rev. ed. 687 p., 478 fig., 31 tables, 14×22 cm. *Holt*, $3.75. This book has been generally regarded as one of the soundest and also one of the best illustrated of the general textbooks of the traditional type. Advantage has been taken of experience with the first edition to improve many statements and methods of presentation of ideas. The problems have been arranged more logically. All of the numerical problems have been changed and many new ones added.

A Class Book of Magnetism and Electricity. H. E. HADLEY, Principal of the School of Science, Kidderminster, England. 522 p., 432 fig., 12×18 cm. *Macmillan*, $2.50. This elementary textbook covers a wide range of good material and should be suitable for an elementary review course to follow general physics. Emphasis is placed on the concepts of the potential and potential difference, rather than on the unsatisfactory analogies to hydrostatic phenomena. Fundamentals are stressed but considerable space is devoted to very recent developments.

Introduction to College Physics. JOHN REMINGTON HOBBIE, Professor of Physics, Skidmore College. 756 p., 495 fig., 14×21 cm. *Farrar & Rinehart*, $3.50. In this book for the general student, the applications selected for emphasis are those that will be of general rather than technical interest. A little more emphasis than usual, however, is given to applications of physics in medicine. Most of the new physics appears at the end of the book. The illustrations are excellent and are in many cases original and novel; for example, in three of the line drawings illustrating chromatic aberration and the formation of rainbows, the rays are shown in their respective colors. The format and binding are good.

College Physics. A. WILMER DUFF, Professor of Physics, Worcester Polytechnic Institute. Ed. 3. 528 p., 502 fig., 27 tables, 14×21 cm. *Longmans, Green*, $3.80. Popularly known as the "Little Duff" and for ten years regarded as one of the most successful textbooks of the concise type, this book now appears in its third edition with a new, brief chapter on recent advances and with numerous revised statements throughout the text. The treatment of electrostatic fields has been improved. Several proofs of expressions have been moved from the appendix to the text proper, where they appear in secondary type. The excellent worked-out examples have been retained. Two complete sets of problems and exercises are provided. Many of the problems are qualitative and unusually illuminating.

A Textbook of Physics. CHARLES A. CULVER, Professor of Physics in Carleton College. 826 p., 525 fig., 14×22 cm. *Macmillan*, $4. Although the generous year course provided by this book is intended primarily for students of the sciences or of their applications, the author believes that it is also suitable for other students since the "presentation involves, among other factors, the arrangement of the material in a natural sequence, and the bringing out of the relation of a new topic to that which has already been studied." "Many texts are seriously defective in this

respect, which probably accounts for a considerable part of the difficulty experienced . . . with . . . physics." Hence the author gives numerous cross references throughout the text; has light follow heat, "since these two subjects are so intimately related through the common factor of radiant energy"; and places sound after electricity because "the study of modern acoustics involves a number of electrical processes and devices." The book contains a number of other minor departures from conventional modes of expression and treatment. A working knowledge of trigonometry is presupposed.

Reference Books for Beginners

Handbook of Chemistry and Physics. Edited by Charles O. Hodgman, Associate Professor of Physics, Case School of Applied Science. Ed. 20. 1951 p., 11×17 cm. *Chemical Rubber Pub. Co.*, $3.00. The best available handbook for use in connection with beginning and undergraduate courses and laboratories. The current edition is still larger than ever and includes new material on x-ray spectra, magneto-optic rotation, colorimetry, photometry and organic chemistry.

Practical Infrared Photography. Othmar Helwich. Tr. from Ger. by J. L. Baring. 93 p., 73 fig., 16×21 cm. *Fountain Press*, 4 s. An interesting, simple description of the materials, technics and applications of infrared photography. Excellent illustrations.

Worlds Without End. H. Spencer Jones, Astronomer Royal of England. 344 p., 11 fig., 32 pl., 13×20 cm. *Macmillan*, $3. This is perhaps the best of the recent popular books on astronomy. It is up-to-date, readable, and free from the pseudometaphysical pretensions of some of the other books of its kind. The illustrations include some 70 telescopic photographs.

Tools of Tomorrow. Jonathan Norton Leonard. 320 p., 22 pl., 14×21 cm. *Viking*, $3. An authentic and expertly written, popular account of the applications of physical science in industry and life and of "the things known to science today that may change our tomorrows." Recommended for students who are interested in the social studies or in commerce.

Intermediate and Advanced Textbooks and References

Heat for Advanced Students. The Late Edwin Edser. Rev. by N. M. Bligh. 487 p., 204 fig., 11×17 cm. *Macmillan*, $1.75. In this revision of a familiar book that first appeared 40 years ago, the most notable change is the introduction of elementary calculus methods in the sections on thermodynamics. Some of the obsolete material has been replaced by modern treatments. The chapter on radiation has been rewritten. There is no improvement in the format.

Dynamics of Rigid Bodies. William Duncan MacMillan, Professor of Astronomy, University of Chicago. 491 p., 82 fig., 15×23 cm. *McGraw-Hill*, $6. The present volume is the last of a series of three textbooks on mechanics by this author. The series is given the traditional name of "Theoretical Mechanics" but really deals with *mathematical mechanics.* As is the case with the two preceding volumes on particles and on potential theory, the treatment is sound and comprehensive, but concise and formal.

Phenomena in High-Frequency Systems. August Hund. 657 p., 359 fig., 32 tables, 15×23 cm. *McGraw-Hill*, $6. A thorough, modern and adequately indexed reference book on phenomena in high-frequency systems and their applications in communication, by an electrical engineer and physicist who is an authority in this branch of applied physics. It is one of the *International Series in Physics*, edited by F. K. Richtmyer.

An Outline of Probability and Its Uses. Maurice C. Holmes, Department of Physics, West Virginia University. 119 p., 21 fig., 13×21 cm. *Edwards Brothers*, lithoprinted, paper, $1.50. A concise, introductory text or manual for students who need a practical knowledge of probability as, for example, in preparation for a course in the kinetic theory of gases. The main topics treated are the fundamental operations, basic concepts and laws, law of large numbers, law of small probability, normal probability curve, mathematical expectations, and probability of causes. Numerous solved and unsolved problems, a brief set of tables and formulas, and a bibliography are included.

Atomic Physics. MAX BORN, Stokes Lecturer in Mathematics, Cambridge University. Tr. and enlarged from Gr. ed. (1933) by John Dougall. 364 p., 136 fig., 10 tables, 15×22 cm. *Stechert*, $4.75. An authoritative and up-to-date survey of atomic physics, with the mathematical details relegated to the last 87 pages. Although hardly suitable as a text for a survey course, the book should be exceedingly useful for purposes of general reading and review. The discussions of many topics—the relation between the two types of statistics, the uncertainty relation, etc.—are relatively brief and elementary, and yet characterized by great clarity. This doubtless is a result of the fact that the author not only knows but understands an immense amount about the field of which he writes and to which he has contributed so much.

Foundations of Physics. ROBERT BRUCE LINDSAY, Associate Professor of Theoretical Physics, Brown University, and HENRY MARGENAU, Assistant Professor of Physics, Yale University. 551 p., 30 fig., 15×23 cm. *Wiley*, $4.50. It seems safe to predict that this book will have a noticeable effect, and may even become something of a landmark, in the development of physics textbooks and teaching, elementary as well as advanced. The book is neither a popular presentation nor an original treatise but an excellent *textbook* on the nature of physical ideas, concepts and laws, the methods of physical description and the structure of theories. In short, the book is concerned with imparting an *understanding* of the science as contrasted with a knowledge of its mathematical and experimental details. To say, with the authors, that the subject dealt with is the philosophical aspects of physical science, gives to our mind an incorrect and unfair picture of what the book really is. The whole methodology of physics is an integral and inseparable part of the science, and to characterize it as "philosophy," in either the popular or classical sense of the term, is not only confusing but fosters the already too prevalent attitude that it is unnecessary for the average physicist to have a critical understanding of the foundation and structure of his science. The book should be studied by every embryo physicist, either independently or in connection with a survey course in mathematical physics, and certainly by every teacher of physics who is not already familiar with the standard works in this field.

We venture to predict that when physical methodology in its elementary aspects is made the essential and unifying theme of the *first-year* general course, then physics will begin to take its rightful place in the minds of both students and educators as one of the most fundamental, useful and interesting of all studies for the purpose of general education. If this happens, physics may take the lead in justifying T. H. Huxley's prediction that the *study* of the sciences will remake the spirit of man, just as science itself is remaking the material world.

HISTORIES

The Discovery of Specific and Latent Heats. DOUGLAS MCKIE, Lecturer in the History and Methods of Science, and NIELS H. DE V. HEATHCOTE, both of University College, London. 155 p., 6 pl., 12×18 cm. *Arnold*, 6 s. As Andrade points out in a Foreword to this monograph, the subject dealt with is really the foundation of the science of heat, which may be said to have begun when a clear distinction was made between *heat* and *temperature*. The treatment is based on a study of the original literature in the original language, and is thorough and scholarly. It is a good source of lecture and reference material for a course on heat. The period covered is from the work of Black (1759) up to Rumford's researches. Particular attention is given to the controversy for priority between supporters of Black and those of Wilcke (sometimes misspelled "Wilke"); apparently Wilcke's work was independent, but was later and less satisfactory than that of Black.

A History of Science, Technology and Philosophy in the 16th & 17th Centuries. A. WOLF, Professor and Head of the Department of History and Methods of Science, University of London. 719 p., 316 fig. and pl., 15×25 cm. *Macmillan*, $7. This ambitious and valuable survey of the developments of thought from the time of the Copernican revolution through the age of Newton covers all the sciences and their applications and has chapters on the social fields and philosophy. The technological sections are particularly comprehensive and valuable. Although competent authorities have found the book not altogether perfect, it is unquestionably superior both in scholarship and in general usefulness to most of the one-volume histories of science. Moreover, it is readable and within the range of the immature student. The book work is good and many of the illustrations are rare.

MISCELLANEOUS

Radio Around the World. A. W. HASLETT, formerly of King's College, Cambridge. 203 p., 7 pl., 22 fig., 12×19 cm. *Cambridge* and *Macmillan*, $1.75. An interesting, popular account of radio, and of its practical problems, future developments and applications in television, medicine, navigation, war and weather forecasting.

Unsolved Problems of Science. A. W. HASLETT, formerly of King's College, Cambridge, 328 p., 1 pl., 13×20 cm. *Macmillan*, $2. The scientific correspondent of the London *Morning Post* has made a rather interesting attempt to show the layman that "The ignorance of science is at least as diverse as its knowledge, and in many ways more interesting." This is an idea that might be exploited to better advantage in the textbooks. The book covers the whole field of science and, except for occasional lapses and wild statements, appears to be an accurate account. The term "weight" is used for *mass* on the ground that intelligibility is of more importance in a popular book than strict precision of meaning. Although the present author uses good judgment in making such departures from scientific usage, one wonders whether this practice in general really promotes intelligibility or just seems to do so.

DIGEST OF PERIODICAL LITERATURE

Physics Teaching

The Training of Industrial Physicists. J. A. Crowther; *J. Sci. Inst.* **13**, 141–3, May, 1936. A conference on the training of industrial physicists was recently sponsored in England by the Institute of Physics (London) and was attended by heads of industrial research departments and university representatives. It was brought out in the discussion that the title "physicist" still is not understood by a large part of the general public and several representatives asked for a definition. Evidently there should be a more intensive effort to educate the public on the meaning and content of physics, and the kind of work that can best be intrusted to the physicist.

The work of the industrial physicist falls into at least three categories: (1) Fundamental or long-range research; industrial application of new discoveries or untried ideas; (2) Development work, including the rapid solution of the small difficulties that arise continually in the factory, and the problems arising in exploiting laboratory technic and apparatus for use in industry; (3) Technical salesmanship.

Fundamental research in the industries is essentially similar to that in the universities. It differs mainly in that university research today is concerned primarily with the acquisition of new knowledge, while industrial research has as its ultimate object the production of commercially useful objects. This distinction would have appeared very small to an older generation of physicists who found considerable interest in devising new ways of doing things. The conference more or less agreed that for fundamental research a training equivalent to graduate work in a university is almost essential.

The greatest divergence of opinion arose on the question of the proper training of physicists for development work. Yet it is in such work, which in the past has been almost entirely in the hands of trained engineers, that most openings are likely to be found for physicists. Some of the industrial representatives, particularly those from the new forms of industry, stated that physicists show a greater knowledge of, and facility to apply, fundamental principles than do men with a purely engineering training; it is easier to train a physicist to become a reasonably competent engineer, than to train an engineer to think as a physicist. The opinion was strong, however, that for real success in development work a man should be qualified on both sides. He might well be given instruction in machine and instrument design, machine drawing, costing, and patent laws. His research training might profitably be concerned with the many subsidiary problems that arise in a department where large-scale research is in progress rather than with the large-scale problems themselves. Such a mixed course is not in accordance with the requirements of the Ph.D. degree, but one representative expressed the opinion that we should discourage students from attaching so much value to the degree and that employers should cease to take the degree into account when engaging men; many students would gain more from special graduate work than from specialized research for the Ph.D. degree. Few of the industrial representatives showed much enthusiasm for the orthodox graduate research training, except for men of outstanding ability. One representative regarded it as a useful test of a man's research ability; the particular nature of the research training is immaterial, "stickability" on the part of the student being what counts. Some believed that the undergraduate should enter development work immediately after graduation, but one representative presented data on some 70 men which seemed to show that those who enter with graduate research experience are the most successful. Academic opinion was strongly in favor of graduate research training because it gives the student time to assimilate what he has previously learned, exposes him to the personal influence, inspiration and guidance of his research professor, and gives him training in research. Such training necessarily is inefficient and this probably could not be tolerated in industry where salaries are being paid and results are needed quickly. An interesting suggestion was that students might advantageously spend portions of their vacations in some industrial laboratory in an unpaid capacity. The Institute has since arranged to place interested students in contact with laboratories where such facilities exist.

A young physicist ordinarily is not taken into industry in any particular category, and hence must expect to make himself useful in any capacity. If he proves to be unsuited for research or development work, he may find an opening in the more scientific side of the sales organization. The possibility of the direct employment of physics graduates in sales departments might repay investigation.

The importance of personality was greatly emphasized. The industrial scientist must be able to get along with his fellows. He must be prepared to study the art of making his subject intelligible to laymen. He must be the sort of man who would be made the captain of a team or the secretary of a club. Sheer intellectual ability is not likely to carry him far unless it is accompanied by those qualities of character that make him readily acceptable to his fellows.

General Education

Transfer of Training and Educational Pseudo-Science. P. T. Orata; *Math. Teacher* **28**, 265–89, May 1935, *Ed. Admin. and Sup.* 241–64, Apr. 1935. In this significant article the author, an instructor in education at Ohio State University, reinterprets the problem of transfer of training by conceiving it, not entirely as a scientific, psychological problem, but fundamentally as an educa-

tional and technological question. He points out that far from being a dead issue, the problem of transfer is more vigorous than ever; of 167 objective studies of it made since 1890, 68 occurred from 1927 to 1935. The general results of all the studies are: 28 percent show *considerable* transfer; 49 percent, *appreciable* transfer; 9 percent, *little* transfer; 4 percent, *none;* 10 percent *both* transfer and interference. Since interference is indicative of negative transfer, it is safe to conclude that all doubts as to the possibilities of transfer of training may be cast away. As for the *agencies* of transfer, 70 percent of the studies indicate that the effect of practice is general and hence that transfer occurs most effectively through *conscious generalization;* the other 30 percent indicate that practice is specific and therefore that transfer takes place through *identical elements.* Not a few investigations support both views.

The difference between the two current views—Thorndike's theory of identical elements and Judd's theory of generalization—is as follows. To Thorndike the identical elements are the *cause* whereas to Judd they are the *effect* of transfer. Judd points out that when two situations are identical the problem of transfer disappears; transfer is the *process of discovering* the identical elements by generalization and application. Thorndike maintains that the identical elements are inherent in nature awaiting notice, whereas Judd holds that they are to be discovered in much the same way as a scientist discovers natural laws. If Thorndike is right then all generalizations should have been made at the beginning of time except those that are due to evolution. In final analysis, Thorndike holds that the identical elements are *logical* in nature, whereas Judd maintains that they are *psychological.* For the former, transfer occurs *automatically* if at all; for the latter, it is very largely *consciously* and *deliberately* worked for.

The studies made during 1927–1935 not only essentially confirm the earlier ones, but advance the frontier of thinking on the problem. In the first place, several studies both of human and of animal learning provide tests of Thorndike's and Judd's rival theories. They show fairly conclusively that the mere presence of identical elements does not guarantee that transfer takes place and that, on the other hand, perfect transfer may take place between two situations that apparently are unrelated. This all goes to show that the occurrence of transfer depends, not upon the presence or absence of hypothetical identical elements whether they be in terms of content, procedure or even ideals, but upon the extent to which the investigator succeeds in setting up the experiment so as to provide conditions favorable to transfer. Thus it is safe to conclude that for the teacher and the school the problem of transfer of training is to *train for transfer.*

Thorndike's own experiments do not support his theory; rather, they were the outcome of the theory which is inherent in the stimulus-response bond hypothesis. In this sense Thorndyke experimented to prove rather than to test his hypothesis and hence his experiments are not scientific but pseudo-scientific, a term used here without the element of derision that is usually attached to it. All studies in education insofar as they make presuppositions as to the *standards of value* to be attained, and they all make such assumptions if they are educational at all, are pseudo-scientific. Indeed it is this very pseudo-scientific nature of educational investigations that can and must humanize education.

The second significant advance on the problem lies in a fundamental change in Thorndike's own position. Indeed, some believe that Thorndike and Judd are now in fundamental agreement on the issue. Thus Sandiford claims that Judd's *generalization of experience* resolves itself simply into the formation of specific habits having applicability to situations other than those in which they were learned. Douglass concludes that to many psychologists a theory of transfer based on the process of generalization is not opposed to one which explains transfer as occurring through identical elements. Suffice it to say that if Thorndike and Judd now are in agreement concerning the meaning and nature of generalization, the change must be in Thorndike, not in Judd.

A third and most important new development is the growing body of factual evidence from animal learning especially with reference to the "mechanism of intelligence." Lashley concludes from his elaborate investigation that: (1) the theory of identical elements finds no support from either neurology or physiological psychology; (2) if there is anything in common between two situations in which transfer occurs, it is not in the elements of the situation, but rather in *relationships* among the elements which are *perceived by some mysterious process of insight;* (3) therefore, contrary to the ordinary view the *theory of formal discipline* is not a dead issue but still an open question. These conclusions find support in many careful studies of animal learning. For example, Alm found from his extensive study of albino rats that the elements transferred were *response patterns,* not specific responses. Obviously if animals do not behave as mechanically as the theory of identical elements requires we can infer that more intelligent man acts even less mechanically. The present tendency in psychology, physiology and in the other sciences to emphasize synthesis more than the traditional notion of analysis lends support to the point of view just indicated.

A fourth development is the recent serious attempt by subject-matter specialists to experiment in the classroom on methods for effecting transfer in their subjects. Although most of these studies indicate its existence, the amount of transfer is very much smaller than was expected. This led many extremists to the startling conclusion that the various subjects of the curriculum have equal educational value. The famous Committee of Ten based its recommendation for the adoption of the well-known "principle of equilitarianism" with respect to secondary school subjects on the assumption that *all subjects competently taught for the same length of time have the same educational value.* Since no standard of competency was defined, "competently taught" only could be taken to mean "as ordinarily taught" and hence the assumption reduced to: A credit of one subject is as good as that of another. The inference is not that a subject like physics is valuable in

itself because it develops abilities that are transferable to life situations, but that abler students taking such subjects cause them to have greater transfer value. From this point of view, bookkeeping has not only as much but actually more training value than Latin, and probably geometry and logic too!

If we grant the premises on which the foregoing inference is based and hence have to accept the conclusion, we need only to inquire further whether the various subjects as "ordinarily taught" are "competently taught." Fortunately there is indisputable evidence from over 40 studies that the objectives of the different school subjects in terms of knowledge and skills are far from having been achieved; that is, students pass algebra without knowing how to solve the problems, or physics without being able to apply the simple formulas learned. Obviously there can be no transfer unless there is something to transfer. Although there are other reasons for lack of transfer, if the students do not know physics after a year's study, it seems absurd to expect them to apply physical principles to the practical affairs of life. The conclusion seems inevitable that since the various subjects as ordinarily taught are not competently taught, the principle of equilitarianism of school subjects must be rejected. From nearly 200 studies showing varying amounts of transfer, it appears that the difference in amount depend on (1) the amount that is available for transfer and (2) the degree to which conditions are made favorable for transfer. While the amount of transfer from the various school subjects is small on the average, the evidence is indisputable that it can be increased enormously.

Educators, as distinguished from psychologists, no longer should limit their inquiry into the possibilities and nature of transfer, but above all should determine whether they want transfer and what provisions to make in methods of learning and teaching and the like in order to realize it in the form and amount desired. Thus the problem for us becomes essentially technological instead of scientific. It is not a matter of finding identical elements by analysis as in the case of the discovery of the law of gravitation, but rather of the creation and construction of attitudes, ideals and beliefs in the light of a desired social value. Instead of a Faraday we need an Edison, for as educators our job is not to discover laws but to make men. As Edison created the electric lamp, we should in like manner create attitudes, ideals, ability to think logically, etc. These are not processes or entities inherent in nature awaiting notice from us, but creations or inventions. We build character—we do not find it. We do not discover that honesty is the best policy, but make it so that it is the best policy. A student should learn his mathematics not by discovering the answers or even proving them, but by analyzing the parts and putting them together again in different patterns in order to arrive at a satisfactory solution. He should not just discover that $22+0$ makes 22, but should add to it his previous experience with $2+0$, with the realization of the principle that zero added to something does not change its value. Without this principle, which is a meaning and a creation rather than an entity or an abstraction, the student may well continue to deal with zero combinations without noticing the "identical elements." Thus one way to teach number combinations is directly by drill, and then the transfer is not only unnecessary but impossible. Another way is to teach the *meaning* of combinations. In fact, the ability to transfer can be generalized so that it can be used to deal with countless fields of interest. This is learning in the broadest sense. It is acting intelligently!

In such higher processes as logical thinking, the phenomena of construction as a process of learning and of transfer become even more apparent. Thinking is no piecemeal activity to be learned by memorizing facts, following the rules of logic in routine fashion, or even dissecting the whole into its constituent elements, important though these processes doubtless are. Rather it is the putting together of the facts in order to solve a problem. Analysis enters in, to be sure, but synthesis is even more important. In fact, analysis is a type of synthesis in the sense that it really involves, not breaking up the situation into its physical parts, but viewing it from different angles. From this point of view transfer is a power, rather than an entity or even a method of a mechanical sort.

Note that *generalization* as used in Judd's theory can be as mechanical as transfer through identical elements, for the student may memorize the rules merely or follow them mechanically. This is the danger of regarding generalization simply as a matter of discovering relations and of stating them in terms of a principle which may be just as verbal. Unfortunately in the realm of social relations generalizations vary with locality and time so that the task is not so much to generalize and apply, as to deal with changing ideals and standards by being willing and able to change previously made generalizations in accord with the needs of a changing social scene; Judd's theory, much less Thorndike's, does not seem to provide for this ability.

For the teacher the problem is to determine what he wants the students to transfer to other fields and to learn by experience or experiment how to teach for transfer. Some of the ways that have been found effective are: conscious formulation of a general principle and application of it to varying situations; discussion and analysis of problems with reference to a point of view; emphasis on meanings and concepts and reconstruction of experience; better organization of material in terms of social issues that are vital to the student. As to the next step in experimentation on the problem, similar considerations apply: decide upon the basic ideals, attitudes, habits and knowledges to be transferred from the school to the social situation and then find by experiment the best means of bringing them about. This approach differs from the present one wherein the investigator in the guise of being objective and scientific views his problems in an unprejudiced manner; that is, without regard to social values to be obtained. If educators recognize this difference, they will avoid scientific pretensions and consequently become more critical of their assumptions and findings, and will be relieved from the false notion that the only way to the truth is by way of statistics and experiments. When so broadly conceived and interpreted, education becomes an art and a technology.

It remains to add that the kind of training that will transfer to the social situation is not obtained, except rarely, by even to most effective study of *formal* subjects. We cannot ignore or be indifferent to the social scene and yet expect the student to be able to deal with it satisfactorily through the medium of his experiences in school. The child may be trained to see the meaning of $2+0$ in the most complicated mathematical problem without being able in the least to see the corresponding social fact that one cannot get anything for nothing. School subjects will result in transfer to the social situation only if, by proper instruction and organization, these subjects are made a "way of life" and are so used by the student himself. This is what is meant by "humanizing education" in the concrete.

The original article contains many other details and includes a bibliography of some 142 articles and books.

The chemistry student still needs a reading knowledge of German. O. E. SHEPPARD; *J. Chem. Ed.* **12**, 472–3, Oct., 1935. An examination of the literature references given in the 1933 volume of the *Journal of the American Chemical Society* shows that of the 5410 citations to 364 different periodicals, 46 percent of the articles were in English, 39 percent in German, 8 percent in French, and 1 percent or less in each of the other languages. By comparing the results of this study with one made in 1927, information on the comparative utility of various journals to American chemists was obtained. If A. C. S. publications are omitted, it was found, for example, that *Annalen der Physik* ranked 7th in importance in 1927 but now ranks 25th, whereas the *Physical Review* formerly ranked 20th but now ranks 6th. It is interesting to note that an approximate classification of over 500 citations in the current *Berichte der deutschen chemischen Gesellschaft* indicates that nearly 90 percent of all citations are in German.

Appointment Service

All correspondence concerning this appointment service should be addressed to the Editor of The American Physics Teacher.

Physicists Available

Representatives of departments or of institutions having vacancies are urged to write for additional information concerning the physicists whose announcements appear here or in previous issues. *The existence of a vacancy will not be divulged to anyone without the permission of the institution concerned.*

6. M.S., N. C. State College; 5 summers grad. work, Univ. of Chicago. Age 39, married. 3 yr. instr. N. C. State College; 5 yr. asst. prof., 7 yr. assoc. prof., Woman's College, University, N. C. Interested in undergraduate teaching or technical research.

7. A.M., A.B., Princeton; 2 yr. additional grad. work in spectroscopy, Princeton and Columbia. Age 30, unmarried. 4 yr. instr. Univ. of Vermont. Special interest in teaching and in developing demonstration and laboratory experiments.

8. Man, 36, married. 15 yr. teaching experience in two eastern universities. Completing Ph.D. thesis in spectroscopy this year at Cornell. Undergraduate teaching experience: demonstration lectures, premedical physics, optics, atomic physics, astronomy, astrophysics.

9. Ph.D. Univ. of Minnesota; S.B., S.M., M. I. T.; 1 yr. grad. work, Univ. of Iowa. Age 38, married, 2 children. 17 yr. teaching experience in universities, colleges and technical schools, including 10 yr. head of department. Interested in progressive undergraduate and graduate teaching and research, including mathematical physics.

10. M.S., B.S., Louisiana State Univ.; 3 yr. graduate work, Cornell; doctorate almost completed. Research in spectroscopy. Age 28, unmarried. 4 yr. instructor, Louisiana. Special interest in teaching and in developing demonstration and laboratory experiments.

Any member of the American Association of Physics Teachers who is not employed in a capacity that makes use of his training in physics may register for this appointment service and have a "Position Wanted" announcement published without charge.

Vacancies

Physicists who are interested in the following vacancies are invited to send to the Editor a brief statement of personal data and professional qualifications:

1. Research positions in the paper industry may be available in the near future. The work, broadly speaking, consists of studies of paper properties and of materials and processes involved in the preparation of pulp and the making of paper.

2. A well-known book publisher is seeking a full-time editor for its scientific publications. Prerequisites include a rather broad training, and teaching experience in both college and secondary school. The position is permanent and offers opportunities for advancement.

3. The College of the Ozarks, Clarksville, Arkansas, wants a Ph.D. to teach physics and mathematics. Address President Wiley Lin Hurie.

Departments having vacancies or industrial concerns needing the services of a physicist are invited to publish announcements of their wants; there is no charge for this service.

Exchange Appointments

1. A professor of physics, Ph.D., in an Ohio college wishes an exchange position for one year, preferably in a western college.